

Noise Analysis of UAV propeller

Thu Nov 15, 2001
c.j.miller@grc.nasa.gov

Overview

In the Navy 2002 SBIR call for proposals is one topic on propellers: N02-096 - "Very Low Noise, High Efficiency Propeller Designs for Small UAVs" [<http://dtica.dtic.mil/sbir/srch/sbir217.html>] (Note the references to ADPAC.) This request seems rather aggressive: equal performance (75% efficiency) but a 12dB (phase I) to 20dB (phase II) noise reduction from current propellers.

Question: Are these reductions reasonable?

Aerodynamic Design

Design Conditions

Questions and some answers from a phone call 11/15/01 with Vince Castelli (CastelliVJ@nswccd.navy.mil). I added more questions later.

Q: Is there more detail on the centerbody shape?

Q: Is the propeller operating in a body wake, wing downwash, or angle of attack?

No, tractor configuration and assume that it is operating at cruise with the axis aligned with the inflow (there still could be some inflow distortion).

Q: What is the noise measurement condition (flyover altitude, rpm, etc.)?

100 ft at the peak radiation angle.

Q: What is the reference noise level of the existing propellers?

Approximately 65 dBA - 70 dBA at 100 ft.

Q: Is the specified 12dB reduction over 5500-9000 rpm a reduction at the peak rpm, or a reduction for all rpm's in that range?

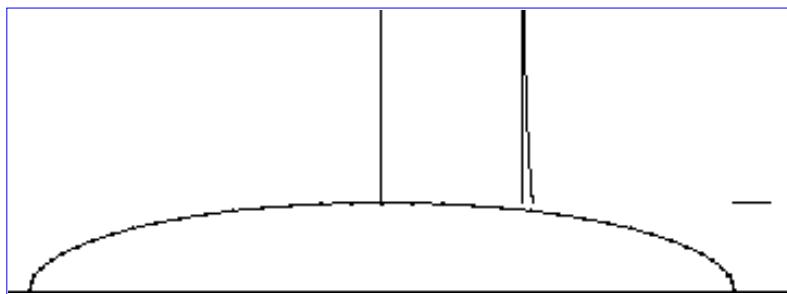
Q: Is a system view allowed, or is this a propeller only approach? If a system view is allowed, is a gearbox allowable as part of the solution? Can the vehicle be changed to reduce the unsteady flowfield or unsteady loads (AOA) seen by the propeller?

Assume that you cannot change the rpm range (i.e. no gearbox changes). Also assume that you can align the propeller axis with the inflow.

Nacelle Shape

The RFP calls for an elliptical centerbody with a 5 inch radius but it leaves the length unspecified. Coordinates were generated for a 4:1 ellipse in metric units and placed in the file [uav.nacelle](#) for use by the XROTOR code. Once read in to XROTOR it a plot of the nacelle and propeller looks like:

4:1 elliptical centerbody with 5" radius



XROTOR Code

XROTOR is a simple (but multi-disciplinary: aero/structures/noise) propeller analysis code developed by Mark Drela of MIT's Aero. & Astro. Department. More information on the code is available at <http://raphael.mit.edu/projects%26research.html>. For licensing information, contact Mark Drela at drela@mit.edu.

XROTOR can be used to get a ballpark design with performance and noise estimates for steady operation. The designs (below) were generated via a shell script [uav.go](#) which means that the user input is not shown in the *.out files. The [xrotor.sample](#) file contains a representative XROTOR session to show the input to and output from the code. User input is in bold.

Initial Design

The XROTOR code was run interactively until a design was found that met the ballpark requirements: efficiency > 75% and a planform that looks roughly like existing model aircraft propellers. In XROTOR design variables this reference design is

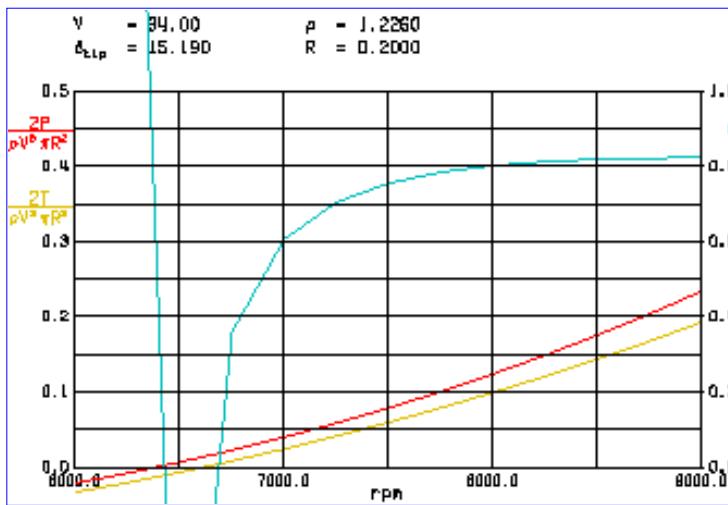
```
b      2      two blades
rt     0.20  [m] tip radius      = 15.75 in diameter
rh     0.0632 [m] hub radius     = 5 in diameter
rw     0.04   [m] wake radius    = 3 in diameter far wake
v      34.0   [m/s] flight velocity = 67 knots
p      420.0  [W] power input    = (selected for ~2 lb thrust)
rpm   8000
cc    0.4    design lift coef.
```

For these values, the straight blade propeller at its' design point has

Thrust = 8.83 N = 1.98 lb
Efficiency = 80.1%

The XROTOR design plot,

Reference design performance.



shows that this design only meets the efficiency requirement for rpm > 7500.

Higher Order Analyses

While XROTOR is sufficient for straight bladed propellers operating in steady conditions, this design task must consider angle of attack, body wakes, wing downwash (all inflow distortions to the propeller). Since this is essentially incompressible (see the [6000-0.4.dsgnpt](#) output discussed below: the tip Mach number is only 0.533), one approach might be a curved lifting line code coupled with a potential panel solution for the centerbody/vehicle. Of approximately the same complexity would be an unsteady panel code like USAERO. More costly would be a finite volume or finite difference code, such as ADPAC (see [http://technology.grc.nasa.gov/software/softwarelist.cfm](#)) which can be used for propeller analysis, but if the unsteady calculation was run as a Navier-Stokes solution instead of an Euler solution, the cost per solution would be prohibitive.

Unconventional Blade Shapes

For general aviation propellers with transonic tip speeds, the two references below examine various techniques for reducing noise and the effect on performance. To summarize: reducing blade tip speed, increasing blade number, blade sweep and tip devices can reduce the steady noise by roughly 4 dBA while incurring no more than about a percent efficiency reduction. If simply increasing the blade number, or reducing the tip speed is not effective, these papers might provide useful background information.

- Miller, C. J.: Optimally Designed Propellers Constrained By Noise. Ph.D. thesis at Purdue University, December 1984.
- Miller, C. J. and Sullivan, J. P.: Noise Constraints Effecting Optimal Propeller Designs. SAE Paper No. 85-0871, April 16-19, 1985. (NASA TM-86967)

Noise Estimates

XROTOR

The XROTOR code has the ability to predict the steady noise for a flyover condition. The current propellers have a noise level of roughly 65-70 dBA at 100 ft, so 100 ft was used for the flyover (0 deg. climb) analysis. Again, the rpm used is 8500.

Design Space

The initial design is not optimum, nor does it work for low values of rpm. The RFP requests an operating range down to 6000 rpm; this initial design windmills

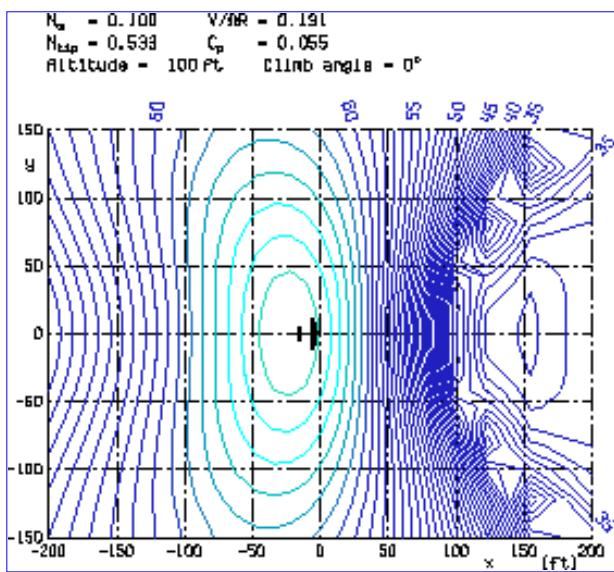
at about 6600 rpm. To solve this problem the design could include variable pitch (via structural deformation) or the design point could be moved to a lower rpm - as is investigated next.

Conventional Propeller Designs

RPM	Design Cl	Windmill RPM	Min RPM for eta > 75%	Peak [dB]	Design Pt Data, XROTOR output, Performance Plots as PS PDF
6000	0.2	<6000	6000-9000	69	dsgnpt, out , ps pdf
6000	0.3	<6000	6000-9000	68	dsgnpt, out , ps pdf
6000	0.4	<6000	6000-9000	67	dsgnpt, out , ps pdf
6500	0.2	6000	6500-9000	66	dsgnpt, out , ps pdf
6500	0.3	<6000	6200-9000	65	dsgnpt, out , ps pdf
6500	0.4	<6000	6000-9000	65	dsgnpt, out , ps pdf
7000	0.2	6400	-	-	dsgnpt, out , ps pdf
7000	0.3	6200	-	-	dsgnpt, out , ps pdf
7000	0.4	5800	6400-9000	62	dsgnpt, out , ps pdf
7500	0.2	6800	-	-	dsgnpt, out , ps pdf
7500	0.3	6500	-	-	dsgnpt, out , ps pdf
7500	0.4	6200	-	-	dsgnpt, out , ps pdf
8000	0.2	7300	-	-	dsgnpt, out , ps pdf
8000	0.3	6900	-	-	dsgnpt, out , ps pdf
8000	0.4	6600	-	-	dsgnpt, out , ps pdf

The best of these straight blade designs seems to be the one designed for 6000 rpm and a design lift coefficient of 0.4. The noise footprint is shown below:

Noise footprint of reference design steady noise for 1000 ft flyover.

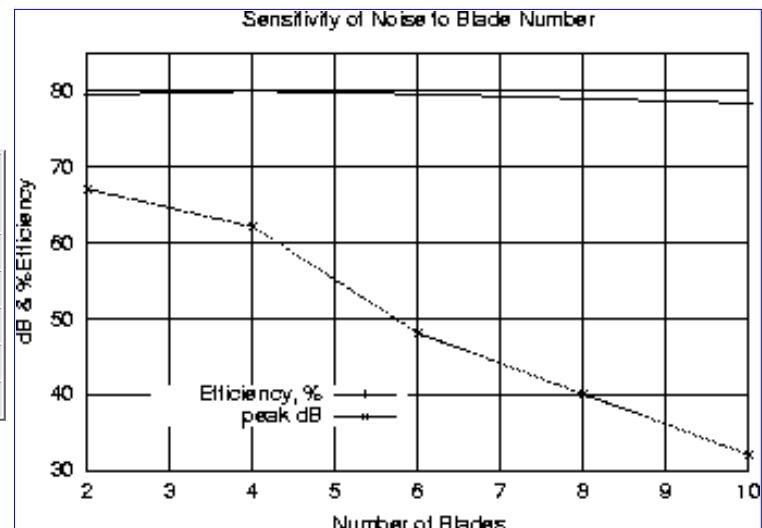


The resulting estimate has a peak of 67dB, which is surprisingly close to the experimental value.

Increasing Blade Number

Starting with the 6000 rpm, Cl=0.4, B=2 design, propellers with higher blade numbers were designed and analyzed:

Noise Reduction from Increasing Blade Number				
Number of Blades	Footprint Peak dB	Efficiency at 8500 rpm	Performance at Design	Plots
2	67	79.4	6000-0.4.dsgnpt	6000-0.4.pdf
4	62	79.9	6000-0.4-4.dsgnpt	6000-0.4-4.pdf
6	48	79.5	6000-0.4-6.dsgnpt	6000-0.4-6.pdf
8	40	78.9	6000-0.4-8.dsgnpt	6000-0.4-8.pdf
10	32	78.3	6000-0.4-10.dsgnpt	6000-0.4-10.pdf



Because of the very low tip speed, most of the energy is in the lowest harmonics of the blade passing frequency. As we increase the number of blades, we drop the lowest harmonics, thereby making drastic reductions in the tone noise. There are two effects at play with the efficiency: increasing the blade number reduces the tip losses, but it also reduces the blade chord lengths. The tip Reynolds number is getting low enough that it is effecting performance.

I appears that a 6-bladed propeller will meet the phase I requirements and that an 8-bladed propeller will meet the phase II requirements.

But, unsteady loading due to

- the propeller at angle of attack,
- unsteady inflow due to wing downwash,
- body flow separation,
- etc.

is a **much** more efficient generator of noise than the steady loading. Because of this, the noise reduction estimates shown above may be wildly optimistic and the noise should be evaluated for possible unsteady loading effects.

WOBBLE Code

A tool for estimating the unsteady loading noise is WOBBLE: written at Hamilton Standard and documented in

Donald B. Hanson and David J. Parzych, "Theory for Noise of Propellers in Angular Inflow With Parametric Studies and Experimental Verification," NASA Contractor Report 4499, Contract NAS3-24222, March 1993.

WOBBLE can be used to estimate the noise from steady loads on a "wobbling" (with respect to the observer) propeller, the real strength is in the ability to put unsteady loads on the wobbling propeller. Since XROTOR doesn't provide unsteady loads, this avenue cannot be pursued at this time.

Summary

This SBIR task seems feasible using nothing more than conventional straight blade propellers, although it requires using more than the current two blades.

TOPIC NUMBER: N02-096

TITLE: Very Low Noise, High Efficiency Propeller Designs for Small UAVs

ADDITIONAL INFORMATION:

Here is a Word file that contains a number of [technical changes for the subject solicitation.](#)

The use of "scimitar-shaped" propeller blades has been identified as a suitable noise reduction technique. Further info is available at: http://www.sae.org/aeromag/techupdate_5-00/16.htm.

Potential offerers may wish to investigate work sponsored by NASA on the PropFan, a scimitar-shaped propeller. The ADPAC Design Code for these blades can be found at: http://technology.grc.nasa.gov/software/SWInfo_form.cfm?SwareKey=5, and its user manual is at: <http://www.grc.nasa.gov/WWW/5900/5940/code/adpac/intro.pdf>. Examples of efforts using this code can be seen at: <http://www.grc.nasa.gov/WWW/5900/5940/code/adpac/adpac.papers.htm>

Mississippi Polymer Technologies, Inc (<http://www.mptpolymers.com/polymers.html>) claims to have the highest strength unfilled polymers available. Though these polymers are still only manufactured in pilot-plant quantities and are currently expensive, they may be of interest to potential contractors for either rapid prototyping or manufacture.

No questions posed on this topic at this time

- [SBIR Question Form](#)

SBIR Topic N02-096

TITLE: Very Low Noise, High Efficiency Propeller Designs for Small UAVs

TECHNOLOGY AREAS: Air Platform, Materials/Processes

DOD ACQUISITION PROGRAM SUPPORTING THIS TOPIC: ACAT IV: PMR 51 – Navy Low/Counterlow Observables Policy, Technology and Projects Office

OBJECTIVE: Develop approaches and designs to reduce the noise associated with propellers for small UAVs to levels consistent with the other components of the propulsion package.

DESCRIPTION: Propellers are fast becoming the dominant noise source in small UAVs. The sources of noise in these small (7"-15") propellers have not been well studied. Most propellers in this size range are designed for and marketed to model aircraft hobbyists who are generally not overly concerned with propeller noise issues since their engine noise is significantly greater. The Navy is developing small UAVs, using either electric or liquid fuel engines, which are significantly quieter than those used by hobbyists. Therefore, propeller noise is becoming a significant issue for these small UAVs. Additionally, the propulsive efficiency of these propellers is important also.

This topic addresses the design and development of novel propeller shapes and configurations that significantly reduce the radiated noise of these small propellers while simultaneously maintaining relatively high propulsive efficiency. Furthermore, since the intended use for the propellers is small, very low cost, expendable UAVs, the final manufactured cost of these low noise propellers must be inexpensive.

PHASE I: Design, fabricate, test, and evaluate low noise propellers (with approximately a 9" dia. X 6" pitch [Note: This has been changed to a propeller delivering 2.0 lbs. of thrust over a 5" diameter elliptical body at 8500 rpm while travelling at a speed of 67 knots]) that can provide a 12 dB average reduction in radiated noise (20 Hz to 20 kHz at 6,000 to 12,500 rpm [Note: Changed to 5,500 to 9,000 rpm]) compared to the best equivalent commercially available [two bladed] propellers being sold in the hobby industry today. Modify designs to provide at least 75% propulsive efficiency over the 8,000 to 10,000 rpm range [Note: Changed to 6,000 to 9,000 rpm]. Select appropriate materials for propeller construction so that it would be expected to remain dimensionally stable to design tolerances after 24 hour exposure to temperatures of 140F and humidity of >60%. Provide an analysis with supporting documentation that explains how final production design will meet or exceed low cost, weight, acoustic, and propulsive efficiency objectives. Provide five propellers for Navy test and evaluation.

PHASE II: Continue development of low noise propellers for small UAVs. Reduce the radiated noise level of the propeller by an additional 8 dB (average, 20 to 20 kHz at 6,000 to 12,500 rpm [Note: Changed to 5,000 to 9,500 rpm]) over the Phase I goals. Maintain propulsive efficiency of at least 75% over the 7,000 to 11,000 rpm range [Note: Changed to 5,500 to 10,000 rpm]. Statistically test propeller construction to ensure that the selected propeller design remains dimensionally stable to design tolerances after 24 hour exposure to temperatures of 140F and humidity of >60%. Measure acoustic performance before and after thermal aging and compare results. Provide an analysis with supporting documentation that explains how final production design will meet or exceed low cost, weight, acoustic, and propulsive efficiency objectives in production. Provide twenty-five propellers for Navy test and evaluation.

PHASE III: Demonstrate production capability with the construction and delivery of 250 propellers. Provide statistical data assessing the acoustic and efficiency performance of at least 25 randomly selected samples. Estimate final cost of production.

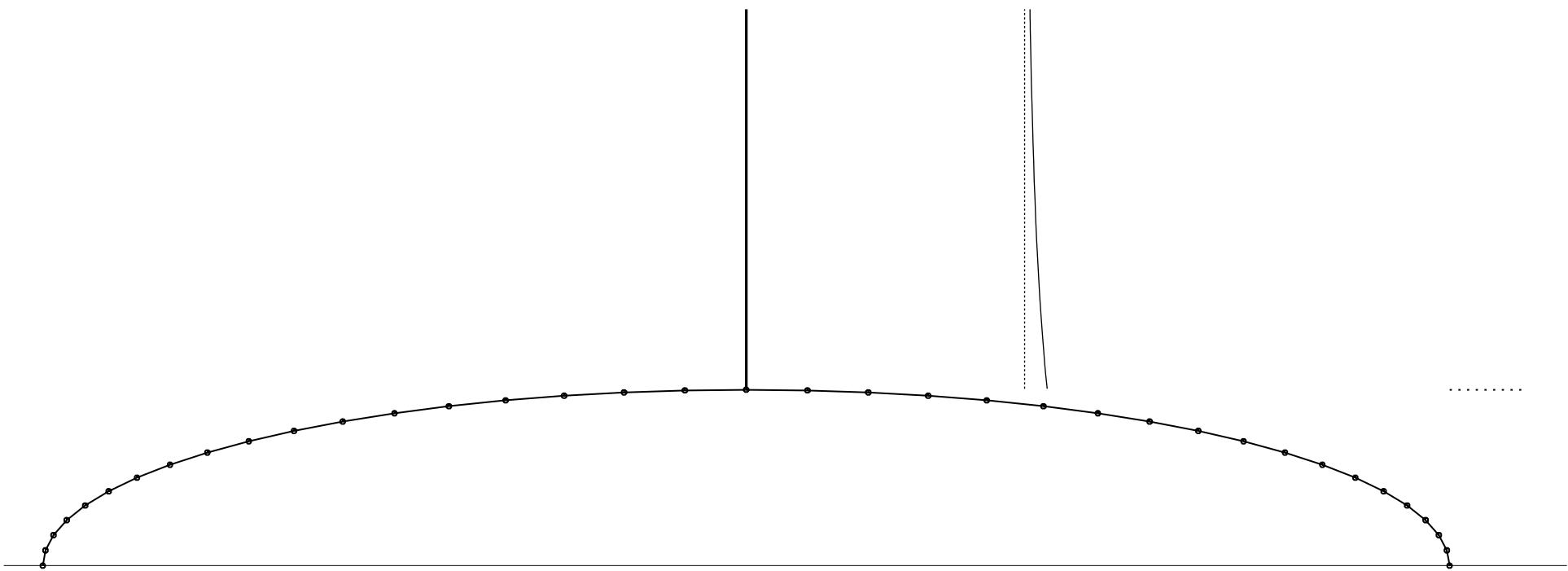
COMMERCIAL POTENTIAL: Improved low noise engine components would be welcomed by the model aircraft hobby market since noise has been a major source of problems with residents adjoining practice flying fields.

KEYWORDS: Propeller, Noise Reduction

TECHNICAL POINT OF CONTACT: Vince Castelli
Phone: 301-227-4960
Fax: 301-227-4814
Email: CastelliVJ@nswccd.navy.mil

2nd TECHNICAL POINT OF CONTACT: Van Olinger
Phone: 703-413-2266 x343
Fax: 703-413-0538
Email: olingev@onr.navy.mil

0.0000000E+00	-6.3199997E-02
-0.2528000	0.0000000E+00
-0.2518379	-5.5082515E-03
-0.2489593	-1.0974572E-02
-0.2441861	-1.6357366E-02
-0.2375543	-2.1615677E-02
-0.2291147	-2.6709475E-02
-0.2189312	-3.1600006E-02
-0.2070816	-3.6250032E-02
-0.1936560	-4.0624171E-02
-0.1787566	-4.4689149E-02
-0.1624967	-4.8414003E-02
-0.1450001	-5.1770400E-02
-0.1264000	-5.4732800E-02
-0.1068379	-5.7278652E-02
-8.6462677E-02	-5.9388552E-02
-6.5429442E-02	-6.1046500E-02
-4.3898262E-02	-6.2239852E-02
-2.2032972E-02	-6.2959500E-02
0.0000000E+00	-6.3199997E-02
2.2032984E-02	-6.2959500E-02
4.3898262E-02	-6.2239852E-02
6.5429464E-02	-6.1046500E-02
8.6462706E-02	-5.9388552E-02
0.1068379	-5.7278652E-02
0.1264000	-5.4732800E-02
0.1450001	-5.1770400E-02
0.1624967	-4.8414011E-02
0.1787566	-4.4689149E-02
0.1936560	-4.0624171E-02
0.2070816	-3.6250032E-02
0.2189312	-3.1599998E-02
0.2291147	-2.6709475E-02
0.2375543	-2.1615669E-02
0.2441861	-1.6357360E-02
0.2489595	-1.0974566E-02
0.2518379	-5.5082422E-03
0.2528000	0.0000000E+00



```
#!/bin/tcsh
# c.j.miller@grc.nasa.gov

foreach B ( 4 )
#foreach RPM ( 6000 6500 7000 7500 8000 )
# foreach CC ( 0.2 0.3 0.4 )
foreach RPM ( 6000 )
    foreach CC ( 0.4 )

        foreach f ( plot.ps uav.designpt uav.rseq )
            if ( -e $f ) /bin/rm $f
        end

        cat<<EOD |grep -v '^#' | xrotor > uav.out
plop
c

desi
edit
b          $B
rt   0.20
rh   0.0632
rw   0.04
v    34.0
p    420.0
rpm      $RPM
cc      $CC

nace uav.nacelle

oper
rpm 8500
write uav.designpt
hard
clrc
rseq 9000 6000 -250
hard

noise
foot 100 0
-200 200
-150 150
21 21
hard

quit
EOD

        cat plot.ps |sed -e "s/plot.ps/$RPM-$CC-$B.ps/" -e 's/*//g' >
$RPM-$CC-$B.ps
        /bin/rm plot.ps
        gs -dBATCH -dNOPAUSE -sDEVICE=pdfwrite -sOutputFile=$RPM-$CC-$B.pdf
$RPM-$CC-$B.ps

        mv uav.out $RPM-$CC-$B.out
        mv uav.designpt $RPM-$CC-$B.dsgnpt
        mv uav.rseq $RPM-$CC-$B.rseq
```

http://roger/~togoode/navy_uav_prop/uav.go

```
    end
  end
end
```

XROTOR Sample I/O

Thu Nov 15 09:47:38 EST 2001

c.j.miller@grc.nasa.gov

XROTOR can be used to get a ballpark design with performance and noise estimates for steady operation. The designs (below) were generated via a shell script [uav.go](#) which means that the user input is not shown in the *.out files. Below is a representative session to show the input to and output from the code. User input is in bold.

```
> xrotor
=====
 XROTOR Version 6.6
=====

OPEN error on file xrotor.def
Hard-wired defaults used

QUIT   Exit program
.AERO  Display or change airfoil characteristics
NAME s Set or change case name

ATMO r Set fluid properties from standard atmosphere
VSOU r Set/change fluid speed of sound
DENS r Set/change fluid density
VISC r Set/change fluid viscosity

NACE f Specify nacelle geometry file
DUCT r Duct/free-tip option toggle
VRAT r Change duct velocity ratio

ARBI  Input arbitrary rotor geometry
.DESI Design rotor geometry
.MODI Modify rotor geometry
.OPER Calculate off-design operating points
.BEND Calculate structural loads and deflections
.NOIS Calculate and plot acoustic signature
.JMAP Calculate Cp vs J operating map

INTE  Interpolate geometry to specified radii
SAVE f Write rotor to restart file
LOAD f Read rotor from restart file
WDEF f Write current settings to xrotor.def file.

VPUT f Save slipstream velocity profiles
VGET f Read slipstream velocity profiles
VCLR  Clear slipstream velocity profiles

HARD  Hardcopy current plot
WIND  Windmill/propeller plotting mode toggle
PLOP  Plotting options

XROTOR c> plop
.....
Size of plot object      10.00"
Aspect ratio of plot object  0.6000
Page dimensions        11.00 x  8.50"
Margins from page edges  0.00",  0.00"
Font size (relative)     0.0140
Window/screen size fraction  0.7000
Blowup input method:    Keyboard
Orientation of plot:    Landscape
Color PostScript output? F

Option, Value (or )    c> c
.....
Size of plot object      10.00"
Aspect ratio of plot object  0.6000
Page dimensions        11.00 x  8.50"
Margins from page edges  0.00",  0.00"
Font size (relative)     0.0140
Window/screen size fraction  0.7000
Blowup input method:    Keyboard
Orientation of plot:    Landscape
Color PostScript output? T

Option, Value (or )    c>
XROTOR c>
XROTOR c> load uav.prop
Self-deforming wake option set
Free-tip option set
Propeller plotting mode set
```

XROTOR Sample I/O

```

1   dG max(i),rms:  0.789E-03 ( 1)  0.315E-04   Av:      0.15279   Aw:      0.16007   Be:      11.70385   RLX:
1.0000
2   dG max(i),rms: -0.169E-05 ( 1)  0.161E-06   Av:      0.15279   Aw:      0.16008   Be:      11.70385   RLX:
1.0000
=====
```

Free Tip Potential Formulation Solution:

		Wake adv. ratio:	0.16008
no. blades :	2	radius(m) :	0.2500
thrust(N) :	9.290	torque(N-m) :	0.4718
Efficiency :	0.7520	speed(m/s) :	34.000
Eff induced:	0.9768	Eff ideal :	0.9838
Tnacel(N) :	0.2157	hub rad.(m) :	0.0632
rho(kg/m ³) :	1.22600	Vsound(m/s) :	340.000
			mu(kg/m-s): 0.1780E-04

```
-----  
Ct:    0.00604    Cp:    0.00386    J:    0.48000
```

i	r/R	c/R	beta(deg)	CL	Cd	Re	Mach	effi	effp	na.u/U
1	0.255	0.0440	36.887	0.400	0.0229	51000	0.199	0.977	0.885	0.0807
4	0.309	0.0399	31.781	0.400	0.0227	53000	0.228	0.977	0.877	0.0638
7	0.410	0.0341	25.160	0.400	0.0224	57000	0.288	0.977	0.857	0.0436
10	0.526	0.0284	20.409	0.400	0.0227	60000	0.360	0.977	0.829	0.0298
13	0.641	0.0235	17.281	0.400	0.0235	59000	0.432	0.977	0.797	0.0212
16	0.746	0.0192	15.187	0.400	0.0250	56000	0.499	0.977	0.763	0.0158
19	0.836	0.0152	13.753	0.400	0.0274	50000	0.557	0.977	0.725	0.0125
22	0.909	0.0113	12.773	0.400	0.0311	40000	0.603	0.977	0.681	0.0105
25	0.961	0.0074	12.138	0.400	0.0374	28000	0.637	0.977	0.628	0.0092
28	0.992	0.0035	11.789	0.400	0.0507	14000	0.657	0.977	0.545	0.0086

```
XROTOR  c> nace uav.nacelle
```

```
Far wake displacement body radius  r/R = 0.2528
```

```
Radial distribution of disturbance velocities:
```

i	Uaxial/V	Uradijal/V	r/R
1	0.08102	0.00000	0.2553
2	0.07851	0.00000	0.2651
3	0.07404	0.00000	0.2835
4	0.06844	0.00000	0.3089
5	0.06242	0.00000	0.3394
6	0.05648	0.00000	0.3737
7	0.05090	0.00000	0.4103
8	0.04582	0.00000	0.4484
9	0.04127	0.00000	0.4873
10	0.03724	0.00000	0.5263
11	0.03370	0.00000	0.5651
12	0.03061	0.00000	0.6034
13	0.02791	0.00000	0.6408
14	0.02556	0.00000	0.6771
15	0.02352	0.00000	0.7122
16	0.02175	0.00000	0.7458
17	0.02021	0.00000	0.7777
18	0.01887	0.00000	0.8079
19	0.01771	0.00000	0.8362
20	0.01672	0.00000	0.8625
21	0.01586	0.00000	0.8868
22	0.01512	0.00000	0.9088
23	0.01450	0.00000	0.9286
24	0.01397	0.00000	0.9461
25	0.01354	0.00000	0.9612
26	0.01319	0.00000	0.9738
27	0.01291	0.00000	0.9840
28	0.01271	0.00000	0.9917
29	0.01258	0.00000	0.9968
30	0.01251	0.00000	0.9994

```
XROTOR  c> hard
```

```
Writing PostScript to file plot.ps ...
```

(Note: The plot files for the design cases have been converted to pdf files for easier viewing in the browser.)

```

XROTOR  c> desi
.DESI  c> edit
      B    2      number of blades
      RT   0.2500  tip radius
      RH   0.0632  hub radius
      RW   0.0400  hub wake displacement body radius
      V    34.0000  airspeed
      A    ---     advance ratio
      R    8500.0020 rpm
      T    ---     thrust
      P    419.9996 power
```

XROTOR Sample I/O

```

CC      0.0000  lift coefficient (constant )
C                  lift coefficient (arbitrary)

..EDIT Parameter, Value (or ) c> cc 0.4
..EDIT Parameter, Value (or ) c>
=====
Free Tip Potential Formulation Solution:
                                              Wake adv. ratio: 0.16096
no. blades : 2          radius(m) : 0.2500  adv. ratio: 0.15279
thrust(N) : 9.299      torque(N-m): 0.4718  power(W) : 420.000
Efficiency : 0.7528    speed(m/s) : 34.000   rpm       : 8500.003
Eff induced: 0.9770    Eff ideal  : 0.9838   Tcoef     : 0.0668
Tnacel(N) : 0.2689    hub rad.(m): 0.0632   disp. rad.: 0.0400
rho(kg/m3) : 1.22600   Vsound(m/s): 340.000  mu(kg/m-s): 0.1780E-04

```

```
-----  
Ct: 0.00605  Cp: 0.00386  J: 0.48000
```

i	r/R	c/R	beta(deg)	CL	Cd	Re	Mach	effi	efffp	na.u/U
1	0.255	0.0438	36.891	0.400	0.0230	51000	0.199	0.977	0.885	0.0810
4	0.309	0.0397	31.878	0.400	0.0228	53000	0.229	0.977	0.877	0.0684
7	0.410	0.0339	25.290	0.400	0.0225	57000	0.288	0.977	0.857	0.0509
10	0.526	0.0283	20.519	0.400	0.0227	60000	0.360	0.977	0.830	0.0372
13	0.641	0.0234	17.365	0.400	0.0235	59000	0.432	0.977	0.798	0.0279
16	0.746	0.0191	15.251	0.400	0.0251	56000	0.499	0.977	0.763	0.0217
19	0.836	0.0151	13.803	0.400	0.0275	49000	0.557	0.977	0.725	0.0177
22	0.909	0.0112	12.815	0.400	0.0312	40000	0.603	0.977	0.682	0.0151
25	0.961	0.0074	12.174	0.400	0.0374	27000	0.637	0.977	0.628	0.0135
28	0.992	0.0035	11.823	0.400	0.0508	14000	0.657	0.977	0.546	0.0127

New rotor geometry created

X-window size changed to 8.48" x 11.00"

B	2	number of blades
RT	0.2500	tip radius
RH	0.0632	hub radius
RW	0.0400	hub wake displacement body radius
V	34.0000	airspeed
A	--	advance ratio
R	8500.0020	rpm
T	9.2896	thrust
P	419.9996	power
CC	0.4000	lift coefficient (constant)
C		lift coefficient (arbitrary)

```

..EDIT Parameter, Value (or ) c> hard
.DESI c> Appending PostScript to file plot.ps ...

```

```

.DESI c>
XROTOR c>
XROTOR c> oper
.OPER c> rpm 8500
  1 dG max(i),rms: 0.794E-03 ( 1) 0.318E-04 Av: 0.15279 Aw: 0.16096 Be: 11.73653 RLX:
1.0000
  2 dG max(i),rms: -0.232E-05 ( 1) 0.225E-06 Av: 0.15279 Aw: 0.16096 Be: 11.73653 RLX:
1.0000
=====
```

Free Tip Potential Formulation Solution:

no. blades	radius(m)	torque(N-m)	power(W)	adv. ratio	na.u/U
2	0.2500	0.4718	419.999	0.15279	0.0810
thrust(N)	9.299				
Efficiency	0.7528	34.000	8500.001		
Eff induced	0.9770	Eff ideal	0.0668		
Tnacel(N)	0.2689	hub rad.(m)	0.0400		
rho(kg/m3)	1.22600	Vsound(m/s)	0.1780E-04		

```
-----  
Ct: 0.00605  Cp: 0.00386  J: 0.48000
```

i	r/R	c/R	beta(deg)	CL	Cd	Re	Mach	effi	efffp	na.u/U
1	0.255	0.0438	36.891	0.400	0.0230	51000	0.199	0.977	0.885	0.0810
4	0.309	0.0397	31.878	0.400	0.0228	53000	0.229	0.977	0.877	0.0684
7	0.410	0.0339	25.290	0.400	0.0225	57000	0.288	0.977	0.857	0.0509
10	0.526	0.0283	20.519	0.400	0.0227	60000	0.360	0.977	0.830	0.0372
13	0.641	0.0234	17.365	0.400	0.0235	59000	0.432	0.977	0.798	0.0279
16	0.746	0.0191	15.251	0.400	0.0251	56000	0.499	0.977	0.763	0.0217
19	0.836	0.0151	13.803	0.400	0.0275	49000	0.557	0.977	0.725	0.0177
22	0.909	0.0112	12.815	0.400	0.0312	40000	0.603	0.977	0.682	0.0151
25	0.961	0.0074	12.174	0.400	0.0374	27000	0.637	0.977	0.628	0.0135
28	0.992	0.0035	11.823	0.400	0.0508	14000	0.657	0.977	0.546	0.0127

X-window size changed to 6.55" x 8.50"

```
.OPER c> write uav.designpt
.OPER c>
```

XROTOR Sample I/O

```
XROTOR  c>  noise
Coordinates currently specified in feet

P   rrr Calculate acoustic p(t) at observer x,y,z
FOOT rr Calculate dB ground noise footprint
NTIM i  Change number of time samples
UNIT   Toggle coordinate unit m,ft

AOC  r  Set constant blade cross-sectional area/c**2
AFIL f  Set blade cross-sectional area/c**2 from file

PLOT i  Plot various acoustic parameters
HARD  Hardcopy current plot
ANNO  Annotate plot
SIZE r  Change plot-object size

.NOIS  c>  foot
Enter footprint x limits (ft):      -4000.      4000.
Enter footprint y limits (ft):      -2000.      2000.
Enter footprint grid size:        21      11

Calculating dB footprint...
1 / 21
2 / 21
3 / 21
4 / 21
5 / 21
6 / 21
7 / 21
8 / 21
9 / 21
10 / 21
11 / 21
12 / 21
13 / 21
14 / 21
15 / 21
16 / 21
17 / 21
18 / 21
19 / 21
20 / 21
21 / 21

X-window size changed to 11.00" x 8.48"

.NOIS  c>  hard
Appending PostScript to file plot.ps ...

.NOIS  c>
XROTOR  c>  oper
.OPER  c>  rseq

Enter first rpm value  r>  6000
Enter last  rpm value  r>  9000
Enter rpm increment    r>  250



| n      | V/wR           | Btip            | V               | rpm       | rho     | mu*1e5  | Vsound  | h       |          |          |      |
|--------|----------------|-----------------|-----------------|-----------|---------|---------|---------|---------|----------|----------|------|
| 1      | 0.2165         | 11.74           | 34.00           | 6000.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 2      | 0.2078         | 11.74           | 34.00           | 6250.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 3      | 0.1998         | 11.74           | 34.00           | 6500.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 4      | 0.1924         | 11.74           | 34.00           | 6750.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 5      | 0.1855         | 11.74           | 34.00           | 7000.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 6      | 0.1791         | 11.74           | 34.00           | 7250.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 7      | 0.1732         | 11.74           | 34.00           | 7500.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 8      | 0.1676         | 11.74           | 34.00           | 7750.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 9      | 0.1623         | 11.74           | 34.00           | 8000.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 10     | 0.1574         | 11.74           | 34.00           | 8250.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 11     | 0.1528         | 11.74           | 34.00           | 8500.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 12     | 0.1484         | 11.74           | 34.00           | 8750.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 13     | 0.1443         | 11.74           | 34.00           | 9000.0    | 1.226   | 1.780   | 340.0   | 999.00  |          |          |      |
| 1      | dG max(i),rms: | 0.350E-03 ( 5 ) | 0.315E-04       | Av:       | 0.21645 | Aw:     | 0.22255 | Be:     | 11.73653 | RLX:     |      |
| 1.0000 | 2              | dG max(i),rms:  | 0.226E-05 ( 1 ) | 0.180E-06 | Av:     | 0.21645 | Aw:     | 0.22254 | Be:      | 11.73653 | RLX: |
| 1.0000 | 1              | dG max(i),rms:  | 0.112E-02 ( 1 ) | 0.663E-04 | Av:     | 0.20779 | Aw:     | 0.21466 | Be:      | 11.73653 | RLX: |
| 1.0000 | 2              | dG max(i),rms:  | 0.184E-05 ( 1 ) | 0.171E-06 | Av:     | 0.20779 | Aw:     | 0.21465 | Be:      | 11.73653 | RLX: |
| 1.0000 | 1              | dG max(i),rms:  | 0.115E-02 ( 1 ) | 0.625E-04 | Av:     | 0.19980 | Aw:     | 0.20844 | Be:      | 11.73653 | RLX: |
| 1.0000 | 2              | dG max(i),rms:  | 0.200E-05 ( 1 ) | 0.178E-06 | Av:     | 0.19980 | Aw:     | 0.20843 | Be:      | 11.73653 | RLX: |
| 1.0000 |                |                 |                 |           |         |         |         |         |          |          |      |


```

XROTOR Sample I/O

	dG max(i),rms:	(1)	0.112E-02	Av:	0.19240	Aw:	0.18038	Be:	11.73653	RLX:		
1.0000	2	dG max(i),rms:	-0.339E-06	(1)	0.295E-07	Av:	0.19240	Aw:	0.18027	Be:	11.73653	RLX:
1.0000	1	dG max(i),rms:	0.103E-02	(1)	0.518E-04	Av:	0.18553	Aw:	0.19002	Be:	11.73653	RLX:
1.0000	2	dG max(i),rms:	0.406E-06	(4)	0.328E-07	Av:	0.18553	Aw:	0.19003	Be:	11.73653	RLX:
1.0000	1	dG max(i),rms:	0.981E-03	(1)	0.471E-04	Av:	0.17913	Aw:	0.18493	Be:	11.73653	RLX:
1.0000	2	dG max(i),rms:	0.287E-06	(4)	0.318E-07	Av:	0.17913	Aw:	0.18493	Be:	11.73653	RLX:
1.0000	1	dG max(i),rms:	0.934E-03	(1)	0.431E-04	Av:	0.17316	Aw:	0.17963	Be:	11.73653	RLX:
1.0000	2	dG max(i),rms:	-0.497E-06	(12)	0.489E-07	Av:	0.17316	Aw:	0.17963	Be:	11.73653	RLX:
1.0000	1	dG max(i),rms:	0.891E-03	(1)	0.396E-04	Av:	0.16757	Aw:	0.17455	Be:	11.73653	RLX:
1.0000	2	dG max(i),rms:	-0.788E-06	(12)	0.838E-07	Av:	0.16757	Aw:	0.17455	Be:	11.73653	RLX:
1.0000	1	dG max(i),rms:	0.854E-03	(1)	0.365E-04	Av:	0.16234	Aw:	0.16974	Be:	11.73653	RLX:
1.0000	2	dG max(i),rms:	-0.114E-05	(11)	0.125E-06	Av:	0.16234	Aw:	0.16974	Be:	11.73653	RLX:
1.0000	1	dG max(i),rms:	0.821E-03	(1)	0.340E-04	Av:	0.15742	Aw:	0.16522	Be:	11.73653	RLX:
1.0000	2	dG max(i),rms:	-0.169E-05	(1)	0.174E-06	Av:	0.15742	Aw:	0.16522	Be:	11.73653	RLX:
1.0000	1	dG max(i),rms:	0.794E-03	(1)	0.318E-04	Av:	0.15279	Aw:	0.16096	Be:	11.73653	RLX:
1.0000	2	dG max(i),rms:	-0.233E-05	(1)	0.225E-06	Av:	0.15279	Aw:	0.16096	Be:	11.73653	RLX:
1.0000	1	dG max(i),rms:	0.771E-03	(1)	0.300E-04	Av:	0.14842	Aw:	0.15696	Be:	11.73653	RLX:
1.0000	2	dG max(i),rms:	-0.303E-05	(1)	0.280E-06	Av:	0.14842	Aw:	0.15696	Be:	11.73653	RLX:
1.0000	1	dG max(i),rms:	0.753E-03	(1)	0.286E-04	Av:	0.14430	Aw:	0.15320	Be:	11.73653	RLX:
1.0000	2	dG max(i),rms:	-0.379E-05	(1)	0.339E-06	Av:	0.14430	Aw:	0.15320	Be:	11.73653	RLX:
1.0000	1	dG max(i),rms:	0.794E-03	(1)	0.318E-04	Av:	0.15279	Aw:	0.16096	Be:	11.73653	RLX:
1.0000	2	dG max(i),rms:	-0.232E-05	(1)	0.225E-06	Av:	0.15279	Aw:	0.16096	Be:	11.73653	RLX:
1.0000												
.OPER	c>	hard	Appending PostScript to file	plot.ps	...							
.OPER	c>	cput uav.rseq										
.OPER	c>											
XROTOR	c>	quit										

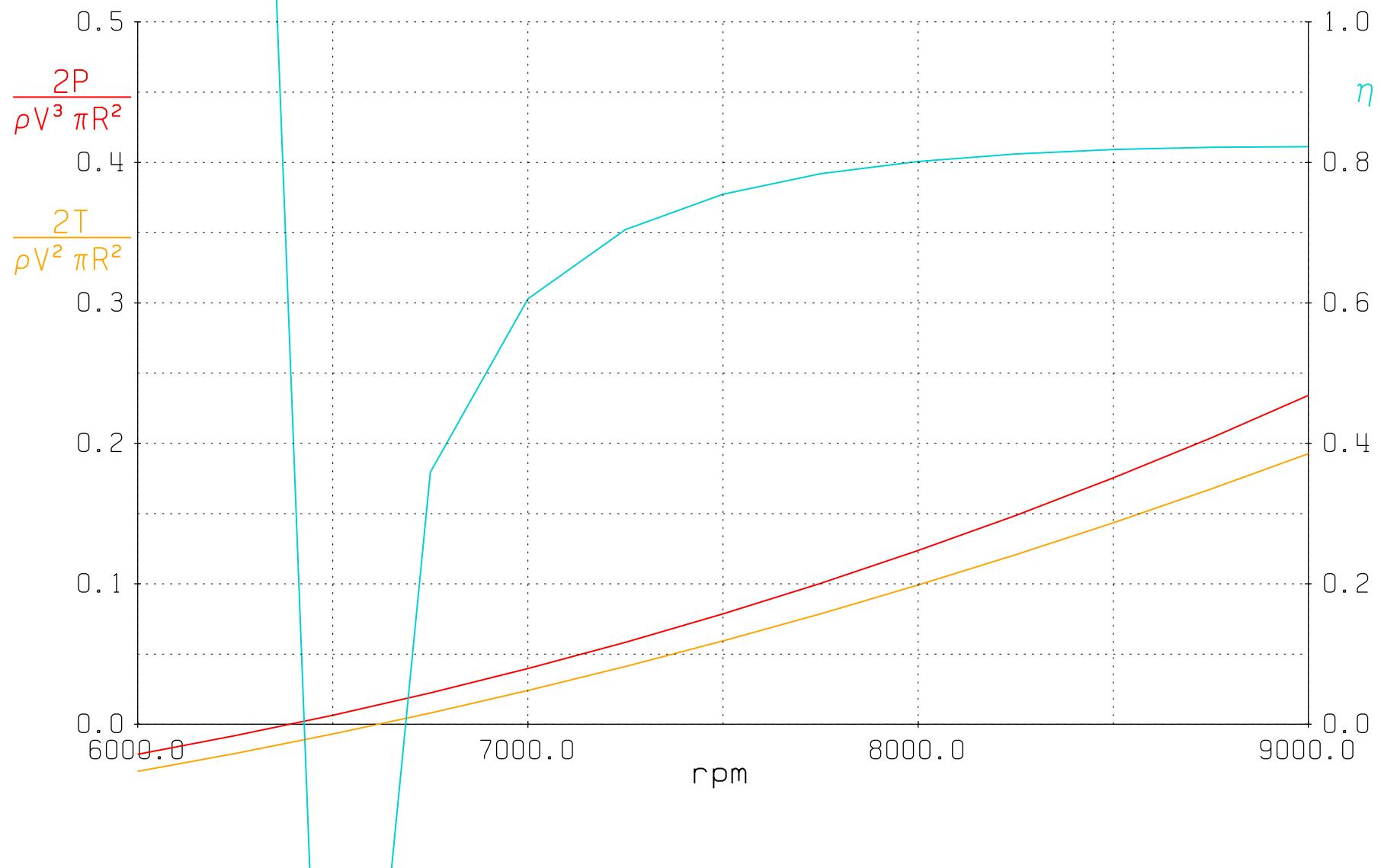
30	2		
1.226000	340.0000	1.7799999E-05	
0.2500000	34.00000	0.1527887	
0.2528000	0.1600000		
0.0000000E+00	6.280000	1.500000	-0.5000000
1.3000000E-02	0.5000000	4.0000002E-03	
200000.0	-0.4000000		
T F F			
0.2553107	4.3979235E-02	0.6438037	8.0707565E-02
0.2650501	4.3040652E-02	0.6256644	7.7122651E-02
0.2834620	4.1592609E-02	0.5938329	7.1040250E-02
0.3088562	3.9890822E-02	0.5546823	6.3839324E-02
0.3394482	3.8029458E-02	0.5137782	5.6551024E-02
0.3736800	3.6070593E-02	0.4746832	4.9741983E-02
0.4103163	3.4078758E-02	0.4391248	4.3648519E-02
0.4484149	3.2111019E-02	0.4076362	3.8323395E-02
0.4872629	3.0207340E-02	0.3801191	3.3731110E-02
0.5263138	2.8389376E-02	0.3562019	2.9799771E-02
0.5651405	2.6664527E-02	0.3354319	2.6447166E-02
0.6034003	2.5030328E-02	0.3173665	2.3592979E-02
0.6408119	2.3478186E-02	0.3016092	2.1164050E-02
0.6771385	2.1996412E-02	0.2878205	1.9096203E-02
0.7121776	2.0572042E-02	0.2757160	1.7334336E-02
0.7457527	1.9192331E-02	0.2650614	1.5831754E-02
0.7777083	1.7845457E-02	0.2556636	1.4549262E-02
0.8079064	1.6521255E-02	0.2473654	1.3454092E-02
0.8362236	1.5211328E-02	0.2400386	1.2518995E-02
0.8625492	1.3909098E-02	0.2335789	1.1721371E-02
0.8867844	1.2609839E-02	0.2279016	1.1042497E-02
0.9088408	1.1310473E-02	0.2229387	1.0466929E-02
0.9286398	1.0009409E-02	0.2186352	9.9819526E-03
0.9461127	8.7063732E-03	0.2149471	9.5771747E-03
0.9611994	7.4024582E-03	0.2118400	9.2441337E-03
0.9738491	6.1005345E-03	0.2092866	8.9760460E-03
0.9840193	4.8066853E-03	0.2072662	8.7675657E-03
0.9916763	3.5352176E-03	0.2057633	8.6146165E-03
0.9967951	2.3334036E-03	0.2047672	8.5142404E-03
0.9993586	1.4219390E-03	0.2042708	8.4645208E-03
1.000000			

$$V = 34.00$$

$$\beta_{tip} = 15.190$$

$$\rho = 1.2260$$

$$R = 0.2000$$



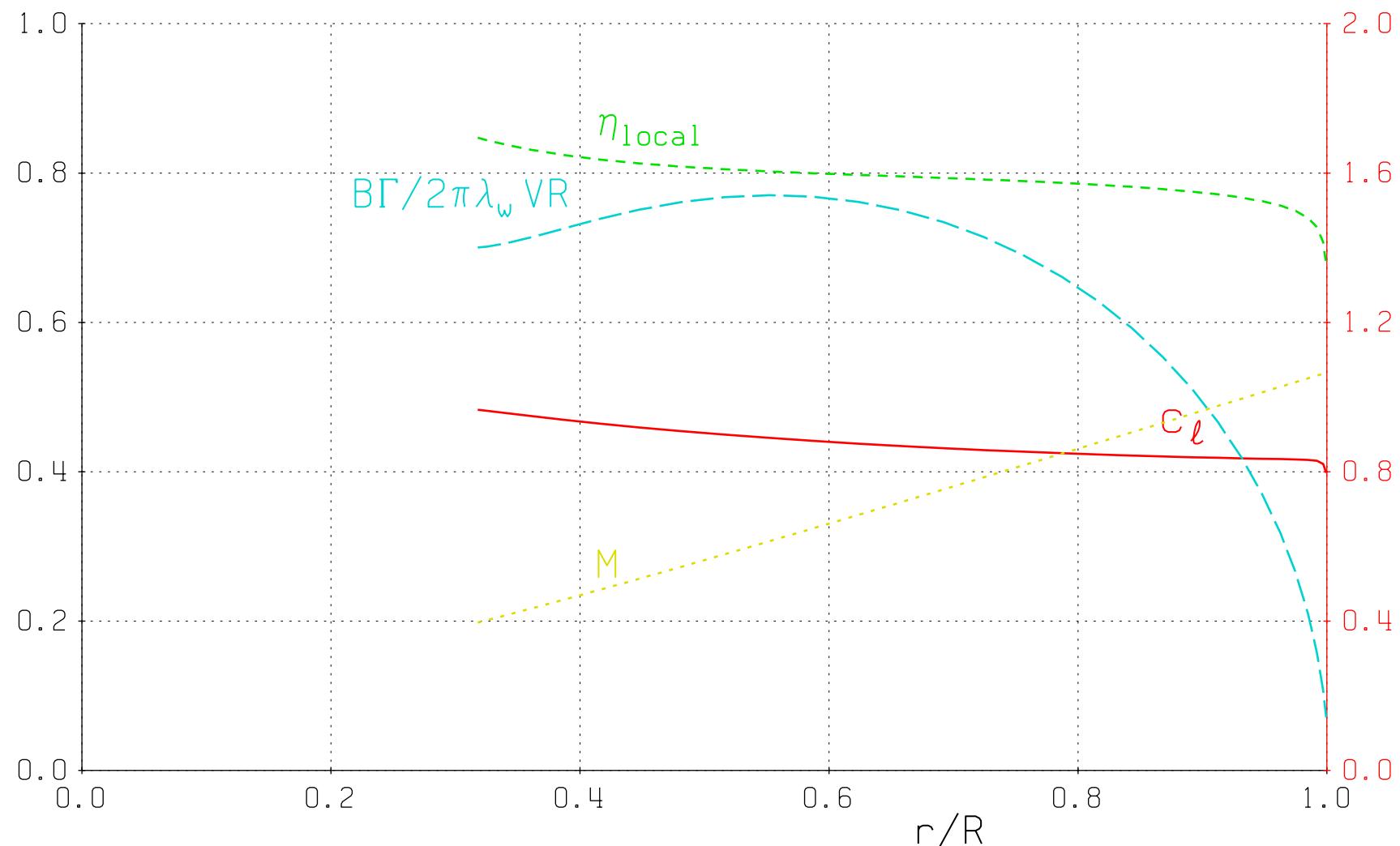
=====
Free Tip Potential Formulation Solution:

no. blades :	2	radius(m) :	0.2000	wake adv. ratio:	0.23513
thrust(N) :	45.508	torque(N-m) :	2.1903	adv. ratio:	0.19099
Efficiency :	0.7936	speed(m/s) :	34.000	power(W) :	1949.594
Eff induced:	0.8400	Eff ideal :	0.8972	rpm :	8500.000
Tnacel(N) :	1.5132	hub rad.(m) :	0.0632	Tcoef :	0.5110
rho(kg/m3) :	1.22600	Vsound(m/s) :	340.000	disp. rad.:	0.0632
				mu(kg/m-s):	0.1780E-04

Ct: 0.07225 Cp: 0.05462 J: 0.60000

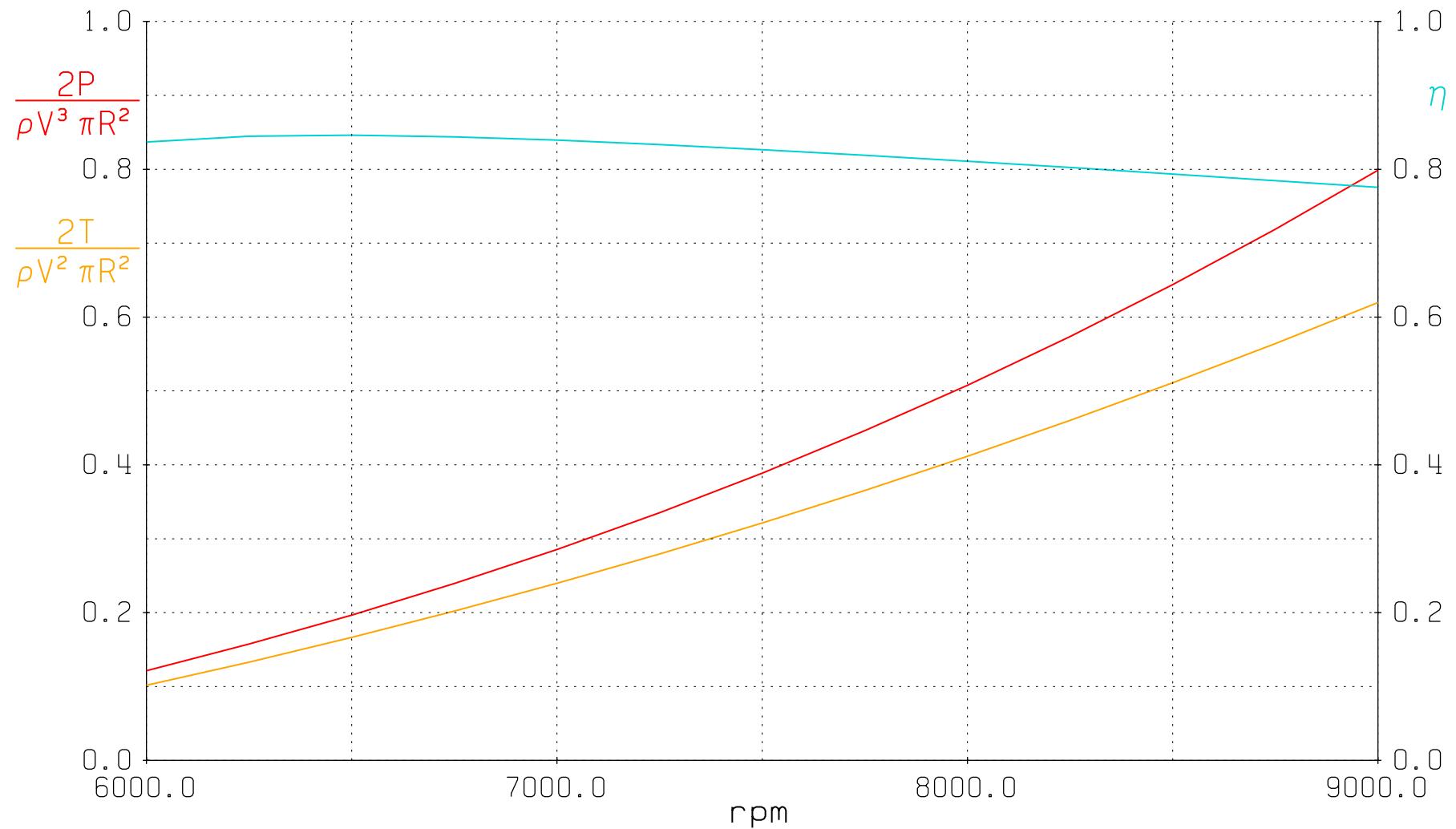
i	r/R	c/R	beta(deg)	CL	Cd	Re	Mach	effi	efffp	na.u/U
1	0.318	0.1991	45.069	0.966	0.0146	185000	0.198	0.874	0.969	0.0813
2	0.326	0.1967	44.455	0.963	0.0146	186000	0.201	0.871	0.969	0.0797
3	0.340	0.1930	43.305	0.958	0.0145	188000	0.208	0.866	0.968	0.0768
4	0.361	0.1887	41.755	0.950	0.0144	192000	0.217	0.859	0.968	0.0729
5	0.386	0.1839	39.959	0.940	0.0142	197000	0.228	0.853	0.967	0.0684
6	0.416	0.1788	38.055	0.929	0.0141	203000	0.242	0.847	0.966	0.0637
7	0.448	0.1732	36.151	0.919	0.0139	208000	0.257	0.843	0.964	0.0591
8	0.481	0.1670	34.319	0.909	0.0138	213000	0.273	0.840	0.963	0.0547
9	0.516	0.1604	32.603	0.899	0.0138	218000	0.290	0.838	0.961	0.0505
10	0.552	0.1533	31.022	0.891	0.0138	220000	0.307	0.837	0.959	0.0467
11	0.588	0.1459	29.582	0.883	0.0138	222000	0.325	0.836	0.957	0.0432
12	0.623	0.1384	28.281	0.876	0.0139	222000	0.342	0.836	0.954	0.0401
13	0.658	0.1307	27.111	0.869	0.0140	220000	0.359	0.836	0.952	0.0372
14	0.692	0.1229	26.062	0.863	0.0141	217000	0.377	0.836	0.949	0.0347
15	0.725	0.1151	25.124	0.858	0.0144	212000	0.393	0.837	0.946	0.0325
16	0.757	0.1074	24.287	0.854	0.0146	206000	0.409	0.837	0.942	0.0305
17	0.787	0.0997	23.541	0.850	0.0150	198000	0.424	0.838	0.939	0.0287
18	0.816	0.0920	22.879	0.846	0.0153	189000	0.439	0.838	0.935	0.0271
19	0.843	0.0844	22.291	0.844	0.0158	179000	0.453	0.839	0.932	0.0257
20	0.868	0.0769	21.773	0.841	0.0163	168000	0.466	0.839	0.928	0.0245
21	0.891	0.0695	21.317	0.839	0.0169	155000	0.477	0.840	0.923	0.0235
22	0.913	0.0621	20.919	0.837	0.0177	142000	0.488	0.840	0.918	0.0226
23	0.931	0.0547	20.575	0.836	0.0186	128000	0.498	0.840	0.913	0.0218
24	0.948	0.0475	20.281	0.835	0.0196	113000	0.506	0.840	0.907	0.0211
25	0.963	0.0403	20.034	0.834	0.0209	97000	0.514	0.840	0.900	0.0206
26	0.975	0.0332	19.832	0.833	0.0226	81000	0.520	0.840	0.892	0.0201
27	0.985	0.0263	19.673	0.832	0.0248	65000	0.525	0.840	0.881	0.0198
28	0.992	0.0195	19.554	0.829	0.0279	48000	0.529	0.839	0.867	0.0195
29	0.997	0.0133	19.476	0.821	0.0325	33000	0.531	0.835	0.847	0.0193
30	0.999	0.0091	19.437	0.797	0.0376	23000	0.533	0.823	0.824	0.0192

$V/\Omega R = 0.1910$	$J = 0.6000$	$\beta_{tip} = 19.437$
$P_C = 0.6439$	$C_P = 0.0546$	$n_{ideal} = 0.8400$
$T_C = 0.5110$	$C_T = 0.0722$	$\eta = 0.7936$



$$\begin{aligned} V &= 34.00 \\ \beta_{tip} &= 19.437 \end{aligned}$$

$$\begin{aligned} \rho &= 1.2260 \\ R &= 0.2000 \end{aligned}$$



$$M_{\infty} = 0.100$$

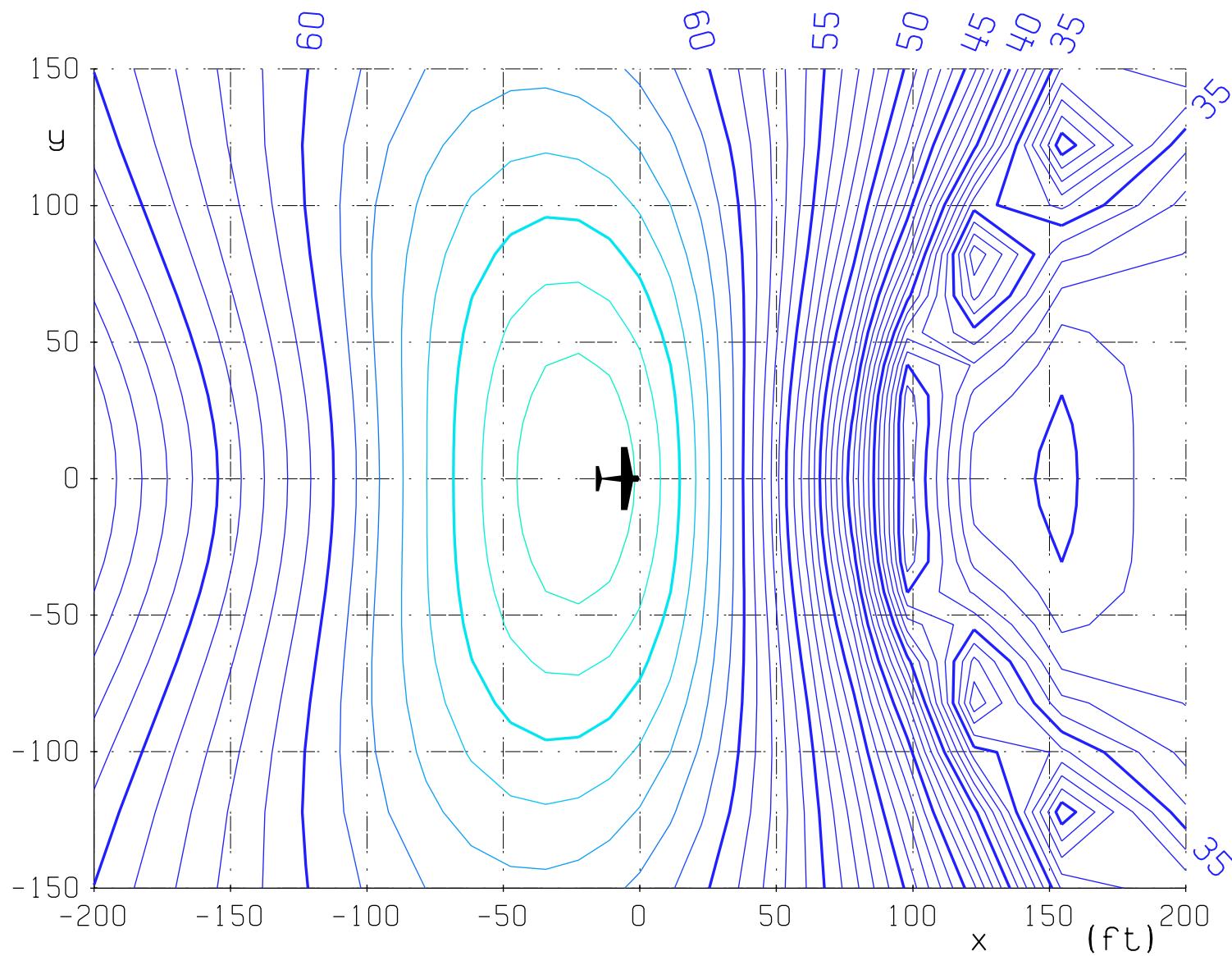
$$V/\Omega R = 0.191$$

$$M_{tip} = 0.533$$

$$C_p = 0.055$$

$$\text{Altitude} = 100 \text{ ft}$$

$$\text{Climb angle} = 0^\circ$$



Free Tip Potential Formulation Solution:

no. blades :	2	radius(m) :	0.2000	wake adv. ratio:	0.24402
thrust(N) :	56.902	torque(N-m) :	2.8595	adv. ratio:	0.19099
Efficiency :	0.7601	speed(m/s) :	34.000	power(W) :	2545.281
Eff induced:	0.8087	Eff ideal :	0.8771	rpm :	8500.000
Tnacel(N) :	1.8469	hub rad.(m) :	0.0632	Tcoef :	0.6390
rho(kg/m3) :	1.22600	Vsound(m/s) :	340.000	disp. rad.:	0.0632
				mu(kg/m-s):	0.1780E-04

Ct: 0.09034 Cp: 0.07131 J: 0.60000

i	r/R	c/R	beta(deg)	CL	Cd	Re	Mach	effi	effp	na.u/U
1	0.318	0.3796	43.219	0.646	0.0106	352000	0.198	0.842	0.967	0.0813
2	0.326	0.3751	42.603	0.644	0.0106	353000	0.201	0.839	0.966	0.0797
3	0.340	0.3680	41.450	0.640	0.0106	358000	0.207	0.834	0.966	0.0768
4	0.361	0.3597	39.898	0.634	0.0105	365000	0.217	0.827	0.965	0.0729
5	0.386	0.3507	38.101	0.626	0.0104	375000	0.228	0.821	0.964	0.0684
6	0.416	0.3409	36.198	0.618	0.0103	386000	0.242	0.816	0.963	0.0637
7	0.448	0.3302	34.296	0.610	0.0103	397000	0.256	0.812	0.961	0.0591
8	0.481	0.3184	32.469	0.602	0.0102	406000	0.273	0.809	0.960	0.0547
9	0.516	0.3057	30.758	0.596	0.0102	414000	0.289	0.807	0.958	0.0505
10	0.552	0.2922	29.183	0.589	0.0102	420000	0.307	0.805	0.955	0.0467
11	0.588	0.2782	27.750	0.584	0.0102	422000	0.324	0.805	0.953	0.0432
12	0.623	0.2637	26.456	0.579	0.0103	422000	0.342	0.804	0.950	0.0401
13	0.658	0.2491	25.293	0.574	0.0104	419000	0.359	0.805	0.947	0.0372
14	0.692	0.2343	24.252	0.570	0.0105	413000	0.376	0.805	0.944	0.0347
15	0.725	0.2195	23.322	0.567	0.0107	404000	0.393	0.805	0.941	0.0325
16	0.757	0.2047	22.492	0.564	0.0109	392000	0.409	0.806	0.937	0.0305
17	0.787	0.1900	21.754	0.561	0.0111	378000	0.424	0.806	0.934	0.0287
18	0.816	0.1754	21.099	0.559	0.0114	361000	0.439	0.807	0.930	0.0271
19	0.843	0.1609	20.519	0.557	0.0118	341000	0.453	0.807	0.926	0.0257
20	0.868	0.1466	20.007	0.555	0.0122	320000	0.465	0.808	0.921	0.0245
21	0.891	0.1324	19.557	0.553	0.0127	296000	0.477	0.808	0.916	0.0235
22	0.913	0.1183	19.165	0.552	0.0132	270000	0.488	0.809	0.911	0.0226
23	0.931	0.1044	18.827	0.551	0.0139	243000	0.498	0.809	0.905	0.0218
24	0.948	0.0905	18.538	0.550	0.0147	215000	0.506	0.809	0.899	0.0211
25	0.963	0.0769	18.295	0.549	0.0156	185000	0.514	0.809	0.891	0.0206
26	0.975	0.0633	18.096	0.548	0.0169	154000	0.520	0.809	0.882	0.0201
27	0.985	0.0501	17.940	0.547	0.0186	123000	0.525	0.809	0.871	0.0198
28	0.992	0.0372	17.824	0.545	0.0209	92000	0.529	0.809	0.855	0.0195
29	0.997	0.0254	17.747	0.540	0.0243	63000	0.531	0.806	0.834	0.0193
30	0.999	0.0174	17.709	0.526	0.0283	43000	0.533	0.800	0.808	0.0192

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Free Tip Potential Formulation Solution:

no. blades :	2	radius(m) :	0.2000	wake adv. ratio:	0.23865
thrust(N) :	50.006	torque(N-m) :	2.4476	adv. ratio:	0.19099
Efficiency :	0.7804	speed(m/s) :	34.000	power(W) :	2178.660
Eff induced:	0.8274	Eff ideal :	0.8890	rpm :	8500.000
Tnacel(N) :	1.6470	hub rad.(m) :	0.0632	Tcoef :	0.5616
rho(kg/m3) :	1.22600	Vsound(m/s) :	340.000	disp. rad.:	0.0632
				mu(kg/m-s):	0.1780E-04

Ct: 0.07939 Cp: 0.06104 J: 0.60000

i	r/R	c/R	beta(deg)	CL	Cd	Re	Mach	effi	effp	na.u/U
1	0.318	0.2609	44.151	0.818	0.0127	242000	0.198	0.861	0.968	0.0813
2	0.326	0.2578	43.535	0.815	0.0127	243000	0.201	0.858	0.968	0.0797
3	0.340	0.2529	42.385	0.810	0.0126	246000	0.208	0.852	0.968	0.0768
4	0.361	0.2472	40.835	0.803	0.0125	251000	0.217	0.846	0.967	0.0729
5	0.386	0.2411	39.038	0.794	0.0124	258000	0.228	0.840	0.966	0.0684
6	0.416	0.2343	37.135	0.784	0.0123	265000	0.242	0.834	0.965	0.0637
7	0.448	0.2270	35.232	0.775	0.0122	273000	0.257	0.830	0.964	0.0591
8	0.481	0.2189	33.403	0.766	0.0121	280000	0.273	0.827	0.962	0.0547
9	0.516	0.2101	31.689	0.758	0.0120	285000	0.290	0.825	0.960	0.0505
10	0.552	0.2009	30.111	0.750	0.0120	289000	0.307	0.824	0.958	0.0467
11	0.588	0.1912	28.674	0.743	0.0121	291000	0.324	0.823	0.955	0.0432
12	0.623	0.1813	27.376	0.737	0.0121	290000	0.342	0.823	0.953	0.0401
13	0.658	0.1712	26.210	0.731	0.0122	288000	0.359	0.823	0.950	0.0372
14	0.692	0.1610	25.164	0.726	0.0124	284000	0.376	0.824	0.947	0.0347
15	0.725	0.1509	24.230	0.721	0.0126	278000	0.393	0.824	0.944	0.0325
16	0.757	0.1407	23.397	0.717	0.0128	270000	0.409	0.825	0.941	0.0305
17	0.787	0.1306	22.655	0.714	0.0131	260000	0.424	0.825	0.937	0.0287
18	0.816	0.1206	21.995	0.711	0.0135	248000	0.439	0.826	0.934	0.0271
19	0.843	0.1106	21.411	0.708	0.0139	235000	0.453	0.826	0.930	0.0257
20	0.868	0.1008	20.896	0.706	0.0143	220000	0.466	0.827	0.925	0.0245
21	0.891	0.0910	20.443	0.704	0.0149	203000	0.477	0.827	0.921	0.0235
22	0.913	0.0813	20.048	0.703	0.0155	186000	0.488	0.828	0.916	0.0226
23	0.931	0.0717	19.707	0.701	0.0163	167000	0.498	0.828	0.910	0.0218
24	0.948	0.0622	19.415	0.700	0.0172	148000	0.506	0.828	0.904	0.0211
25	0.963	0.0528	19.170	0.699	0.0184	127000	0.514	0.828	0.897	0.0206
26	0.975	0.0435	18.970	0.698	0.0199	106000	0.520	0.828	0.888	0.0201
27	0.985	0.0344	18.812	0.697	0.0218	85000	0.525	0.828	0.877	0.0198
28	0.992	0.0256	18.695	0.695	0.0246	63000	0.529	0.827	0.863	0.0195
29	0.997	0.0175	18.617	0.688	0.0286	43000	0.531	0.824	0.842	0.0193
30	0.999	0.0119	18.579	0.668	0.0332	30000	0.533	0.814	0.818	0.0192

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Free Tip Potential Formulation Solution:

no. blades :	2	radius(m) :	0.2000	wake adv. ratio:	0.23175
thrust(N) :	41.079	torque(N-m) :	1.9951	adv. ratio:	0.19099
Efficiency :	0.7865	speed(m/s) :	34.000	power(W) :	1775.875
Eff induced:	0.8526	Eff ideal :	0.9055	rpm :	8500.000
Tnacel(N) :	1.3832	hub rad.(m) :	0.0632	Tcoef :	0.4613
rho(kg/m3) :	1.22600	Vsound(m/s) :	340.000	disp. rad.:	0.0632
				mu(kg/m-s):	0.1780E-04

Ct:	0.06522	Cp:	0.04975	J:	0.60000
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i	r/R	c/R	beta(deg)	CL	Cd	Re	Mach	effi	effp	na.u/U
1	0.318	0.3305	40.918	0.527	0.0112	307000	0.198	0.882	0.957	0.0813
2	0.326	0.3263	40.305	0.526	0.0112	308000	0.201	0.879	0.956	0.0797
3	0.340	0.3195	39.163	0.523	0.0111	311000	0.208	0.874	0.956	0.0768
4	0.361	0.3116	37.632	0.520	0.0111	317000	0.217	0.869	0.955	0.0729
5	0.386	0.3029	35.868	0.515	0.0110	324000	0.228	0.864	0.953	0.0684
6	0.416	0.2935	34.012	0.511	0.0109	332000	0.242	0.859	0.952	0.0637
7	0.448	0.2833	32.169	0.506	0.0109	341000	0.257	0.856	0.950	0.0591
8	0.481	0.2723	30.407	0.502	0.0108	348000	0.273	0.853	0.948	0.0547
9	0.516	0.2607	28.765	0.498	0.0108	354000	0.290	0.851	0.945	0.0505
10	0.552	0.2486	27.261	0.495	0.0108	358000	0.307	0.850	0.942	0.0467
11	0.588	0.2362	25.897	0.491	0.0109	359000	0.325	0.849	0.939	0.0432
12	0.623	0.2235	24.670	0.488	0.0110	358000	0.342	0.849	0.935	0.0401
13	0.658	0.2108	23.570	0.486	0.0111	355000	0.360	0.849	0.932	0.0372
14	0.692	0.1981	22.587	0.483	0.0112	349000	0.377	0.849	0.928	0.0347
15	0.725	0.1854	21.711	0.481	0.0114	341000	0.393	0.850	0.924	0.0325
16	0.757	0.1728	20.931	0.479	0.0116	331000	0.409	0.850	0.919	0.0305
17	0.787	0.1604	20.237	0.477	0.0119	319000	0.425	0.850	0.915	0.0287
18	0.816	0.1480	19.622	0.476	0.0122	304000	0.439	0.851	0.910	0.0271
19	0.843	0.1358	19.078	0.474	0.0126	288000	0.453	0.851	0.904	0.0257
20	0.868	0.1237	18.599	0.473	0.0130	270000	0.466	0.852	0.899	0.0245
21	0.891	0.1117	18.178	0.472	0.0135	250000	0.477	0.852	0.893	0.0235
22	0.913	0.0998	17.811	0.471	0.0141	228000	0.488	0.852	0.886	0.0226
23	0.931	0.0880	17.494	0.470	0.0148	205000	0.498	0.852	0.879	0.0218
24	0.948	0.0764	17.223	0.470	0.0157	181000	0.507	0.853	0.871	0.0211
25	0.963	0.0648	16.997	0.469	0.0167	156000	0.514	0.853	0.862	0.0206
26	0.975	0.0534	16.811	0.469	0.0181	130000	0.520	0.853	0.851	0.0201
27	0.985	0.0422	16.664	0.468	0.0199	104000	0.525	0.853	0.837	0.0198
28	0.992	0.0313	16.556	0.467	0.0224	77000	0.529	0.852	0.818	0.0195
29	0.997	0.0212	16.484	0.464	0.0261	53000	0.532	0.851	0.792	0.0193
30	0.999	0.0143	16.448	0.454	0.0307	36000	0.533	0.846	0.761	0.0192

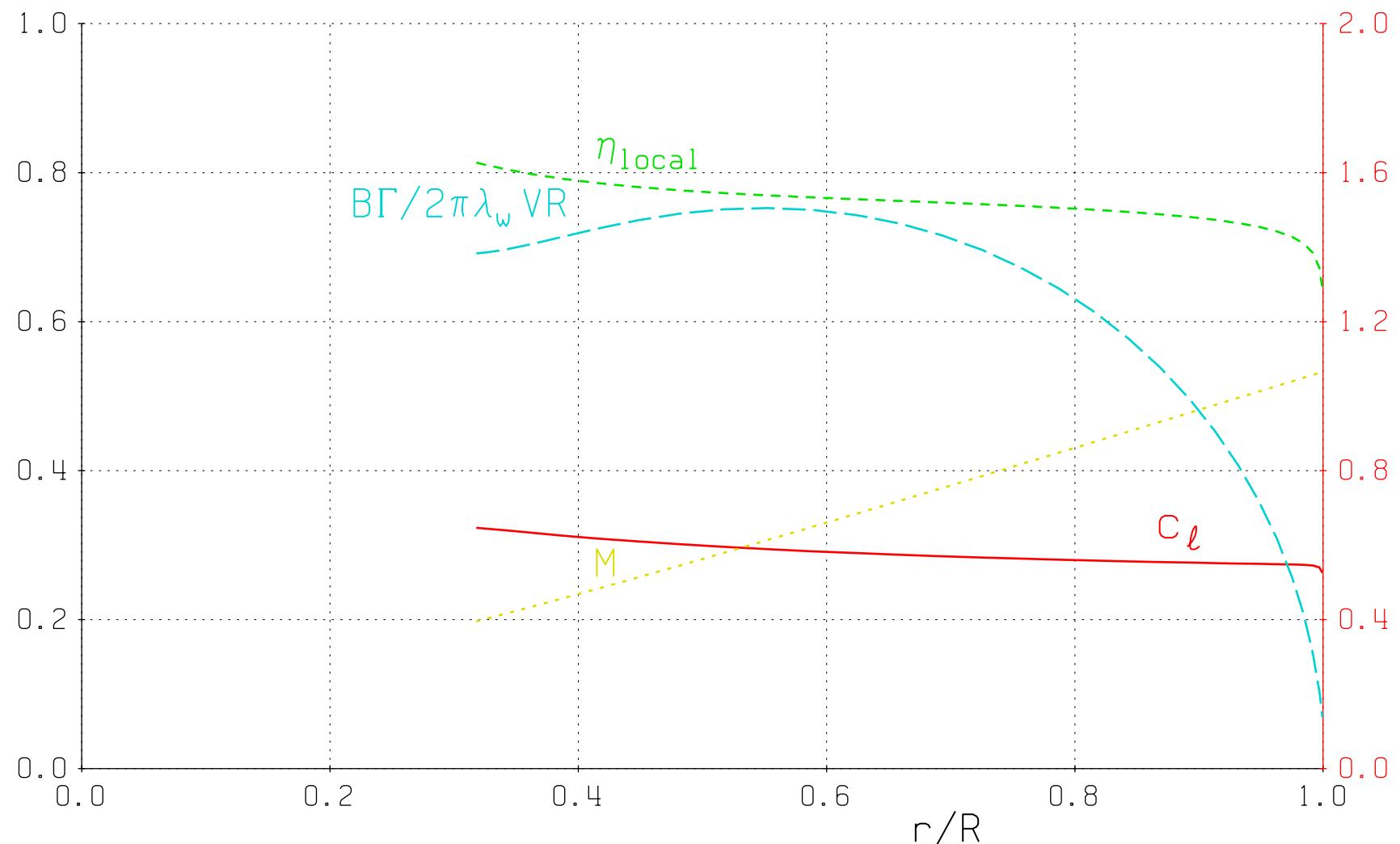
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Free Tip Potential Formulation Solution:

no. blades :	2	radius(m) :	0.2000	wake adv. ratio:	0.22822
thrust(N) :	36.628	torque(N-m) :	1.7397	adv. ratio:	0.19099
Efficiency :	0.8042	speed(m/s) :	34.000	power(W) :	1548.506
Eff induced:	0.8661	Eff ideal :	0.9141	rpm :	8500.000
Tnacel(N) :	1.2457	hub rad.(m) :	0.0632	Tcoef :	0.4113
rho(kg/m3) :	1.22600	Vsound(m/s) :	340.000	disp. rad.:	0.0632
				mu(kg/m-s):	0.1780E-04

Ct: 0.05815 Cp: 0.04338 J: 0.60000

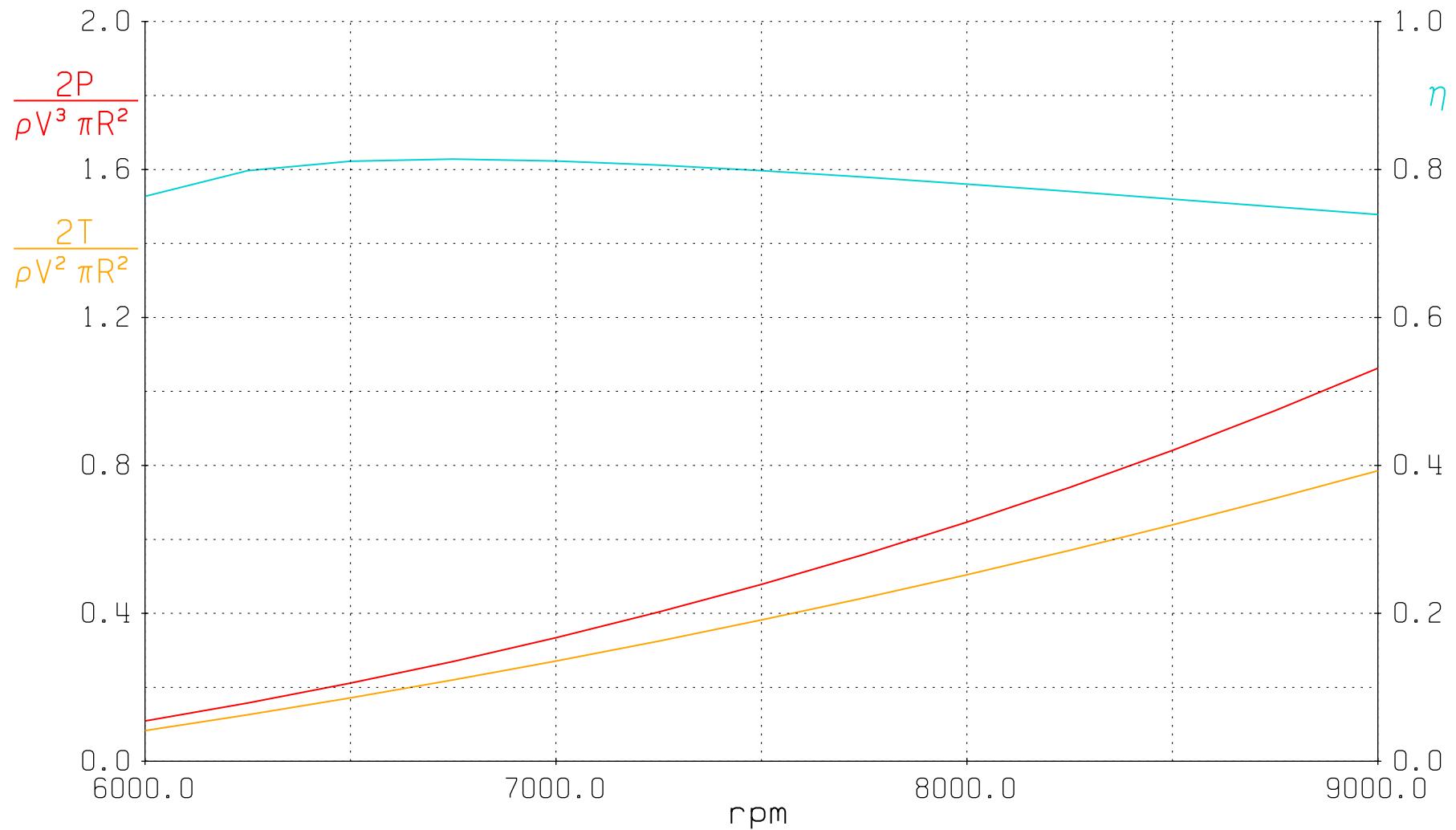
i	r/R	c/R	beta(deg)	CL	Cd	Re	Mach	effi	efffp	na.u/U
1	0.318	0.2280	41.850	0.675	0.0131	212000	0.198	0.895	0.960	0.0813
2	0.326	0.2251	41.238	0.674	0.0131	213000	0.202	0.892	0.960	0.0797
3	0.340	0.2205	40.098	0.671	0.0130	215000	0.208	0.888	0.959	0.0768
4	0.361	0.2150	38.569	0.667	0.0130	219000	0.217	0.882	0.958	0.0729
5	0.386	0.2090	36.805	0.662	0.0129	224000	0.229	0.877	0.957	0.0684
6	0.416	0.2025	34.948	0.657	0.0128	230000	0.242	0.872	0.956	0.0637
7	0.448	0.1955	33.103	0.651	0.0127	235000	0.257	0.869	0.954	0.0591
8	0.481	0.1879	31.339	0.646	0.0126	240000	0.273	0.866	0.952	0.0547
9	0.516	0.1799	29.694	0.641	0.0126	244000	0.290	0.864	0.949	0.0505
10	0.552	0.1716	28.186	0.637	0.0126	247000	0.307	0.863	0.947	0.0467
11	0.588	0.1630	26.818	0.633	0.0127	248000	0.325	0.863	0.944	0.0432
12	0.623	0.1543	25.586	0.629	0.0128	247000	0.342	0.863	0.941	0.0401
13	0.658	0.1455	24.481	0.625	0.0129	245000	0.360	0.863	0.937	0.0372
14	0.692	0.1367	23.494	0.622	0.0131	241000	0.377	0.863	0.933	0.0347
15	0.725	0.1280	22.613	0.619	0.0133	236000	0.393	0.863	0.930	0.0325
16	0.757	0.1193	21.828	0.617	0.0136	229000	0.409	0.864	0.926	0.0305
17	0.787	0.1107	21.130	0.614	0.0139	220000	0.425	0.864	0.921	0.0287
18	0.816	0.1022	20.511	0.612	0.0142	210000	0.439	0.865	0.917	0.0271
19	0.843	0.0937	19.962	0.611	0.0147	199000	0.453	0.865	0.912	0.0257
20	0.868	0.0854	19.478	0.609	0.0152	186000	0.466	0.865	0.907	0.0245
21	0.891	0.0771	19.054	0.608	0.0158	172000	0.478	0.866	0.901	0.0235
22	0.913	0.0689	18.683	0.607	0.0164	158000	0.488	0.866	0.895	0.0226
23	0.931	0.0608	18.363	0.606	0.0173	142000	0.498	0.866	0.888	0.0218
24	0.948	0.0527	18.090	0.606	0.0183	125000	0.507	0.866	0.881	0.0211
25	0.963	0.0447	17.860	0.605	0.0195	108000	0.514	0.866	0.872	0.0206
26	0.975	0.0369	17.673	0.604	0.0210	90000	0.520	0.866	0.862	0.0201
27	0.985	0.0291	17.524	0.604	0.0231	72000	0.525	0.866	0.849	0.0198
28	0.992	0.0216	17.415	0.603	0.0261	53000	0.529	0.866	0.831	0.0195
29	0.997	0.0147	17.342	0.598	0.0304	36000	0.532	0.863	0.807	0.0193
30	0.999	0.0099	17.306	0.585	0.0356	25000	0.533	0.856	0.778	0.0192

$V/\Omega R = 0.1910$	$J = 0.6000$	$\beta_{tip} = 17.709$
$P_C = 0.8407$	$C_P = 0.0713$	$n_{ideal} = 0.8087$
$T_C = 0.6390$	$C_T = 0.0903$	$\eta = 0.7601$



$$\begin{aligned} V &= 34.00 \\ \beta_{tip} &= 17.709 \end{aligned}$$

$$\begin{aligned} \rho &= 1.2260 \\ R &= 0.2000 \end{aligned}$$



$$M_{\infty} = 0.100$$

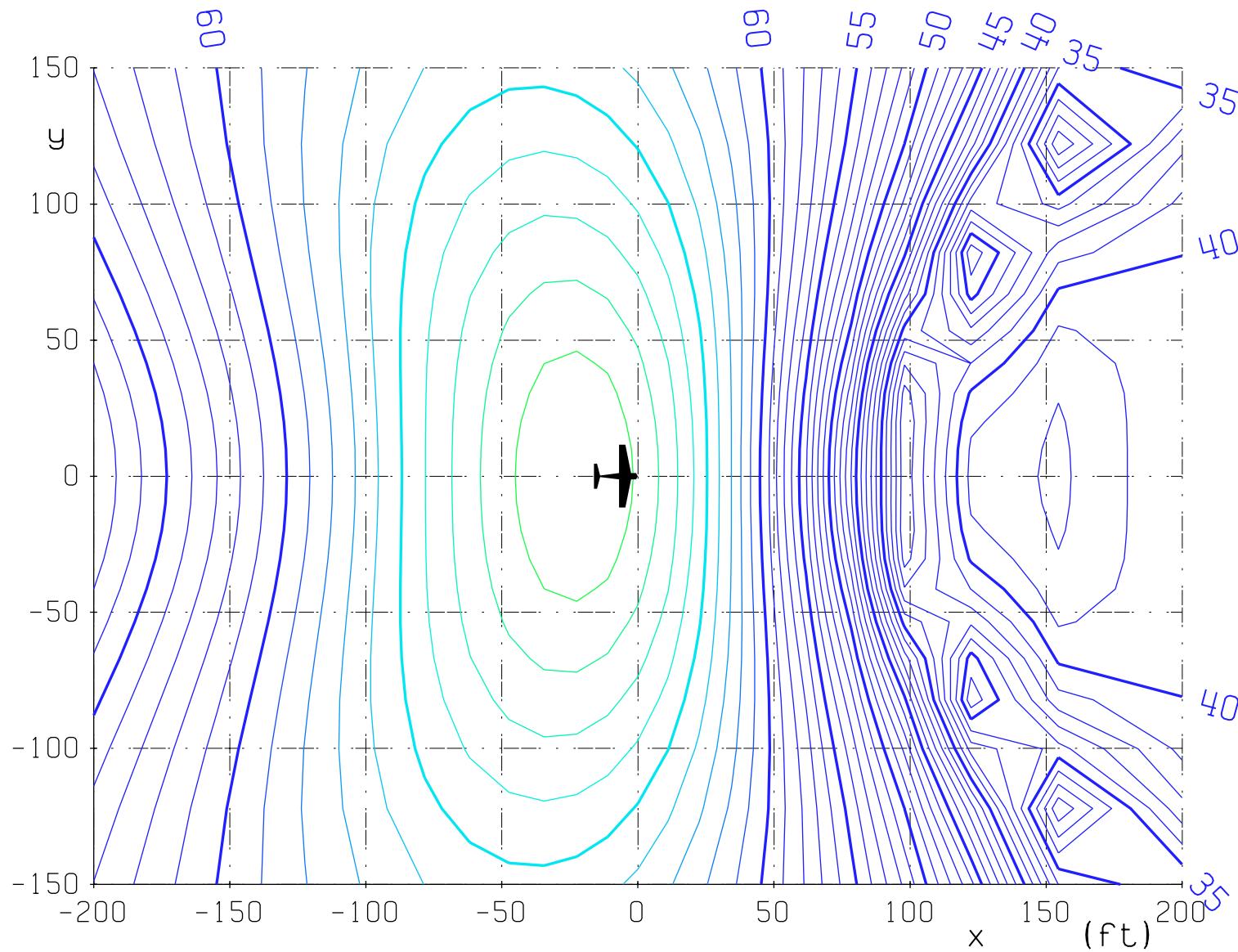
$$V/\Omega R = 0.191$$

$$M_{tip} = 0.533$$

$$C_p = 0.071$$

$$\text{Altitude} = 100 \text{ ft}$$

$$\text{Climb angle} = 0^\circ$$



$$V/\Omega R = 0.1910$$

$$J = 0.6000$$

$$\beta_{\text{tip}} = 18.579$$

$$P_C = 0.7196$$

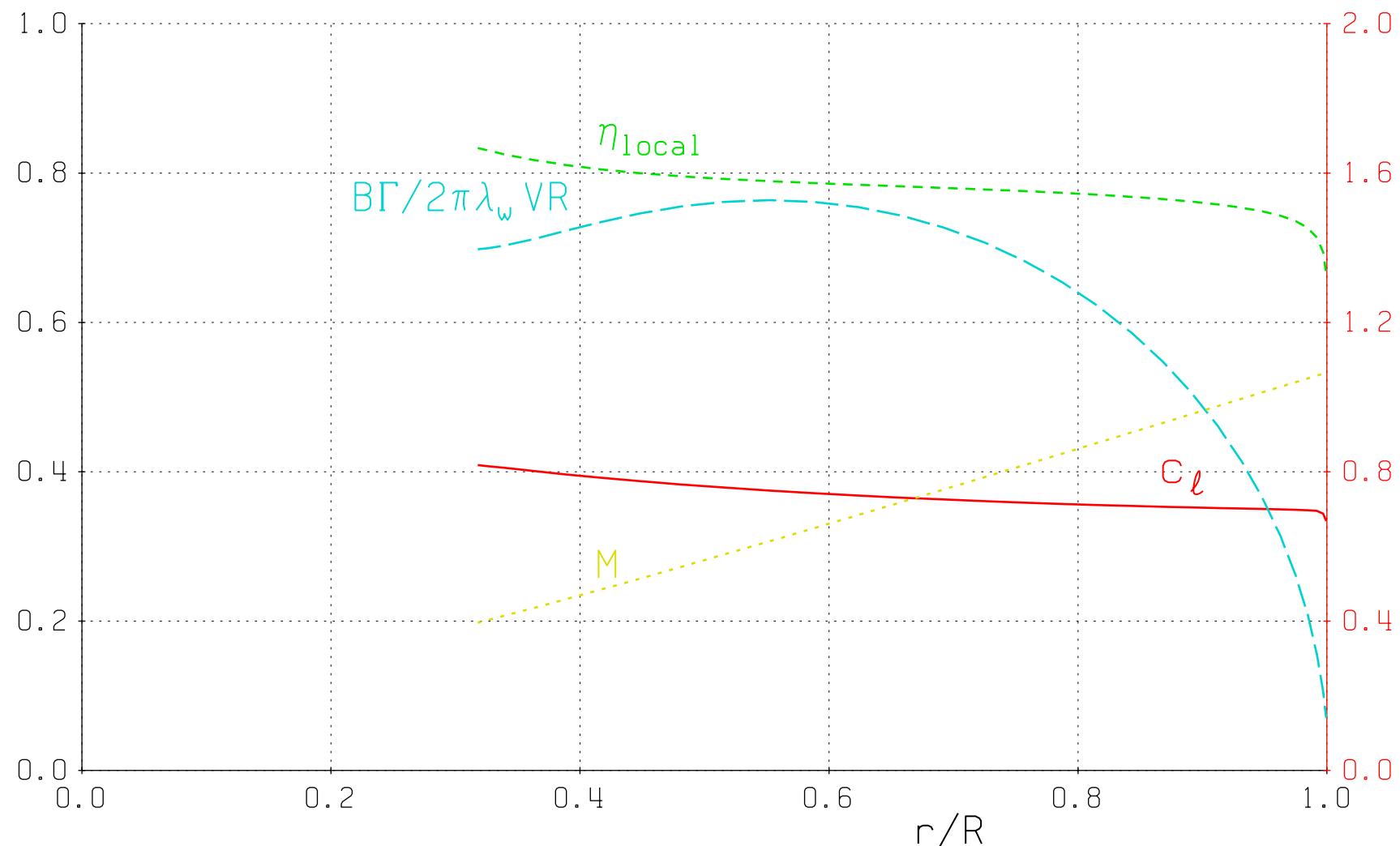
$$C_P = 0.0610$$

$$n_{\text{ideal}} = 0.8274$$

$$T_C = 0.5616$$

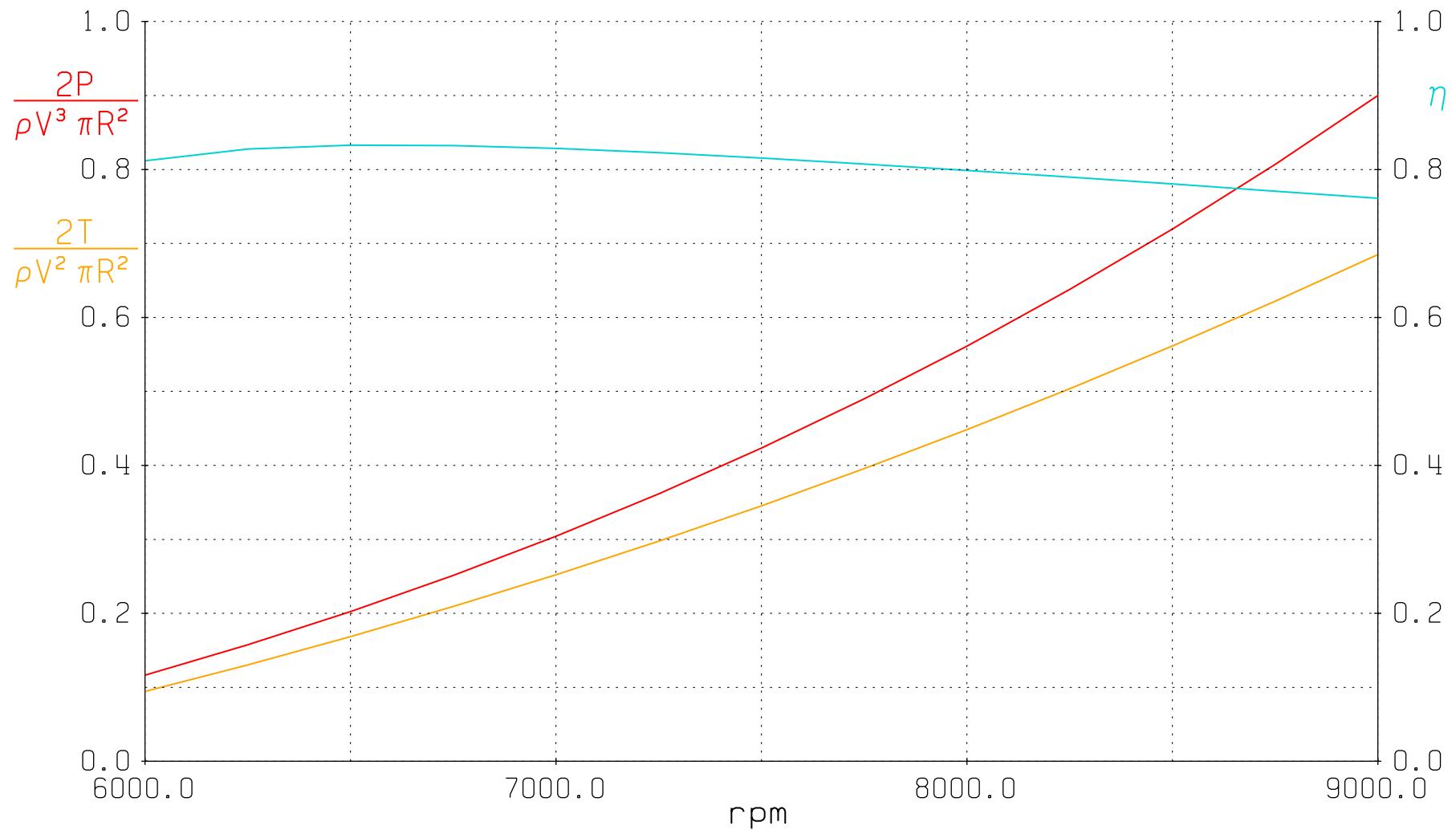
$$C_T = 0.0794$$

$$\eta = 0.7804$$



$$\begin{aligned} V &= 34.00 \\ \beta_{tip} &= 18.579 \end{aligned}$$

$$\begin{aligned} \rho &= 1.2260 \\ R &= 0.2000 \end{aligned}$$



$$M_{\infty} = 0.100$$

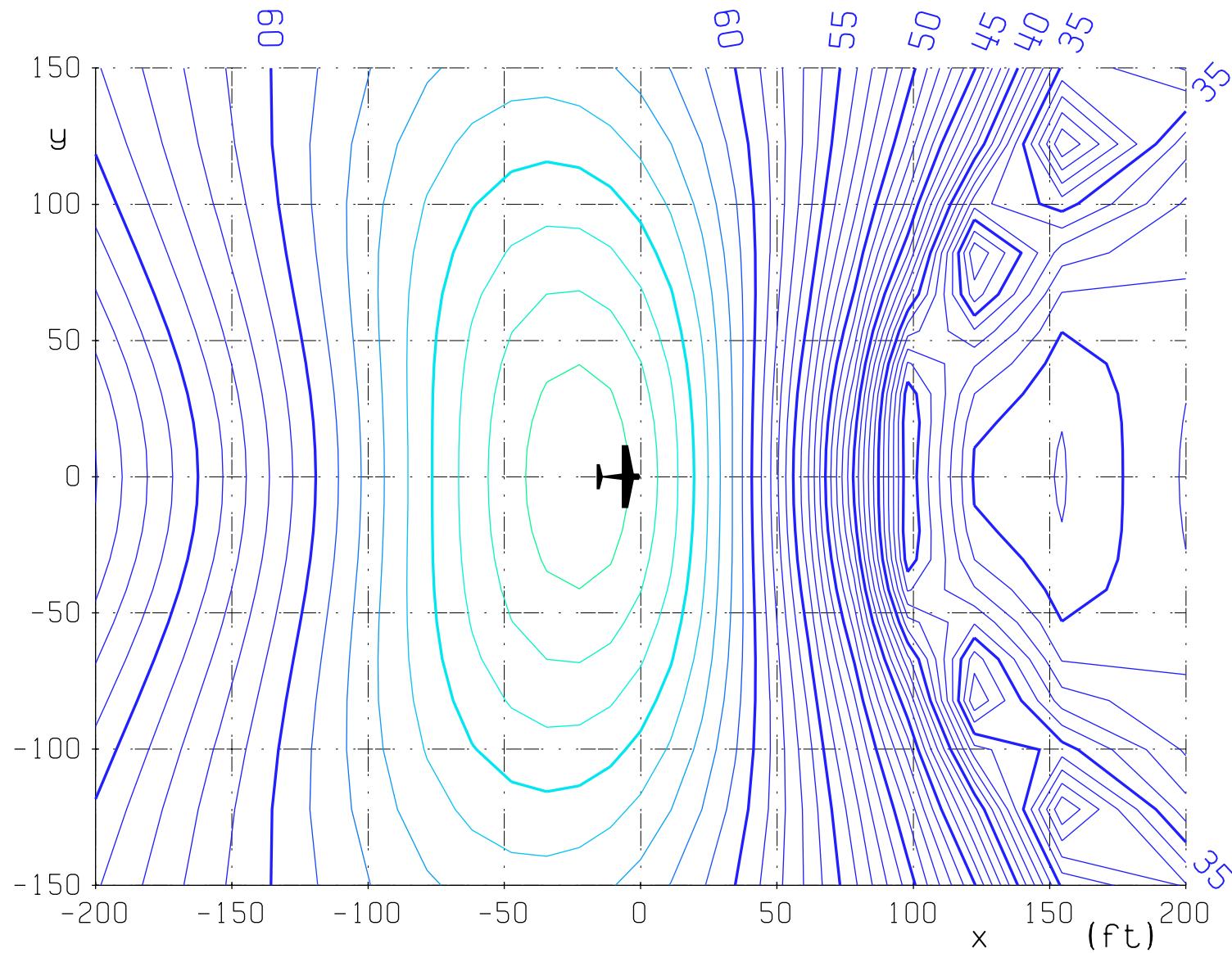
$$V/\Omega R = 0.191$$

$$M_{tip} = 0.533$$

$$C_p = 0.061$$

$$\text{Altitude} = 100 \text{ ft}$$

$$\text{Climb angle} = 0^\circ$$



$$M_{\infty} = 0.100$$

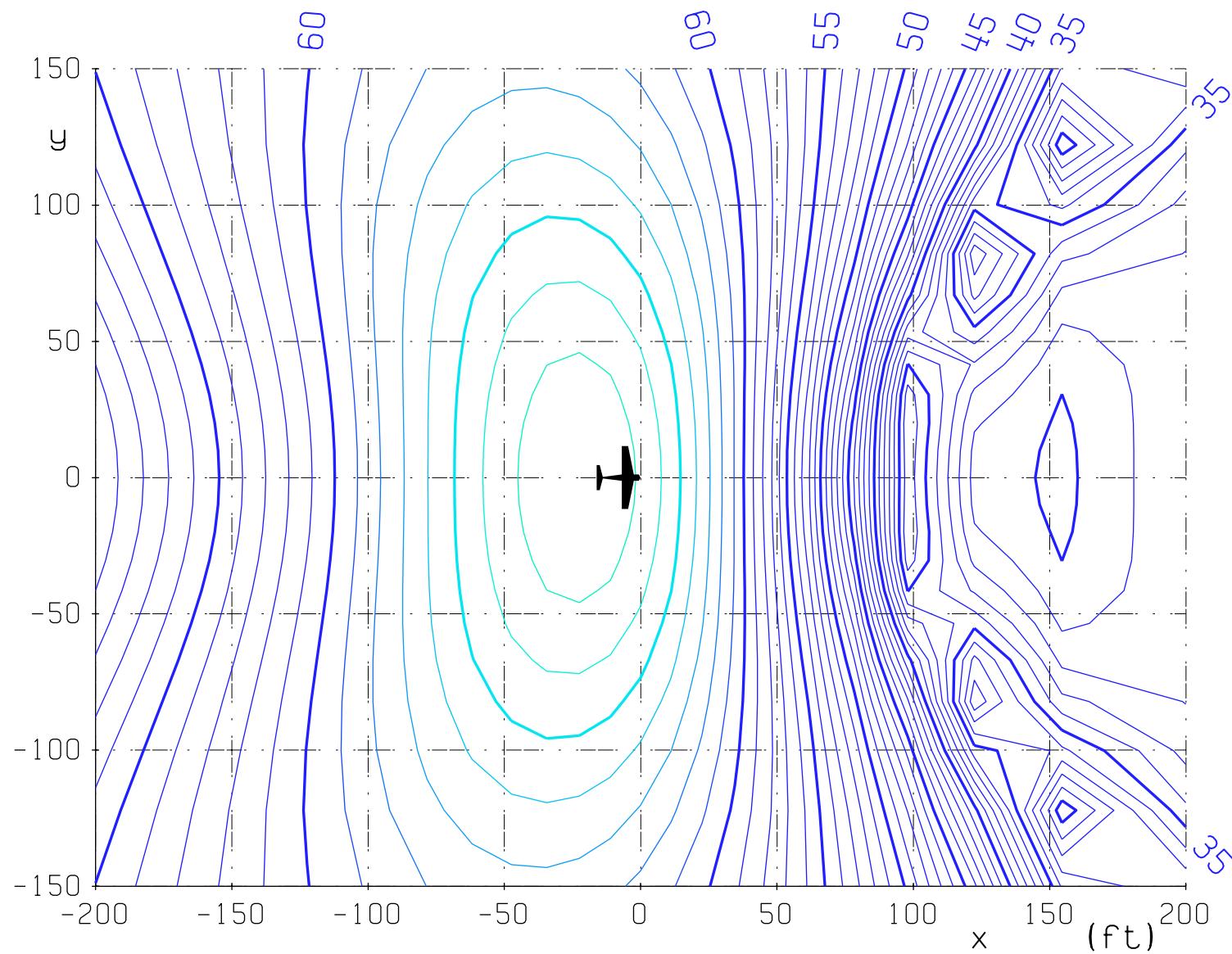
$$V/\Omega R = 0.191$$

$$M_{tip} = 0.533$$

$$C_p = 0.055$$

$$\text{Altitude} = 100 \text{ ft}$$

$$\text{Climb angle} = 0^\circ$$



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Free Tip Potential Formulation Solution:
                                Wake adv. ratio: 0.22882
no. blades : 4                  radius(m) : 0.2000    adv. ratio: 0.19099
thrust(N)   : 45.702            torque(N-m): 2.1848    power(W)  : 1944.742
Efficiency  : 0.7990           speed(m/s) : 34.000    rpm       : 8500.000
Eff induced : 0.8626           Eff ideal   : 0.8968    Tcoef     : 0.5132
Tnacel(N)   : 1.4907           hub rad.(m): 0.0632    disp. rad.: 0.0632
rho(kg/m3)  : 1.22600          Vsound(m/s): 340.000   mu(kg/m-s): 0.1780E-04

-----
Ct: 0.07256      Cp: 0.05448      J: 0.60000

  i   r/R   c/R   beta(deg)   CL   Cd   Re   Mach   effi   effp   na.u/U
  1  0.318  0.0757  44.836   1.010  0.0218  70000  0.198  0.896  0.956  0.0813
  2  0.326  0.0749  44.209   1.007  0.0217  71000  0.202  0.893  0.956  0.0797
  3  0.340  0.0741  43.040   1.000  0.0215  72000  0.208  0.888  0.955  0.0768
  4  0.361  0.0736  41.470   0.990  0.0212  75000  0.217  0.881  0.954  0.0729
  5  0.386  0.0734  39.657   0.978  0.0208  79000  0.229  0.875  0.954  0.0684
  6  0.416  0.0732  37.742   0.966  0.0203  83000  0.242  0.870  0.952  0.0637
  7  0.448  0.0728  35.834   0.953  0.0199  88000  0.257  0.866  0.951  0.0591
  8  0.481  0.0721  34.003   0.940  0.0195  92000  0.273  0.863  0.949  0.0547
  9  0.516  0.0709  32.290   0.928  0.0192  96000  0.290  0.861  0.947  0.0505
 10 0.552  0.0694  30.716   0.917  0.0190 100000  0.307  0.859  0.945  0.0467
 11 0.588  0.0676  29.284   0.907  0.0189 103000  0.325  0.858  0.942  0.0432
 12 0.623  0.0654  27.991   0.898  0.0188 105000  0.342  0.858  0.939  0.0401
 13 0.658  0.0631  26.829   0.890  0.0188 106000  0.360  0.858  0.936  0.0372
 14 0.692  0.0605  25.789   0.883  0.0189 107000  0.377  0.858  0.933  0.0347
 15 0.725  0.0578  24.859   0.877  0.0190 106000  0.393  0.859  0.929  0.0325
 16 0.757  0.0549  24.029   0.872  0.0192 105000  0.409  0.859  0.926  0.0305
 17 0.787  0.0519  23.291   0.868  0.0195 103000  0.425  0.860  0.922  0.0287
 18 0.816  0.0487  22.634   0.864  0.0199 100000  0.439  0.861  0.918  0.0271
 19 0.843  0.0454  22.053   0.862  0.0203  96000  0.453  0.862  0.914  0.0257
 20 0.868  0.0420  21.539   0.860  0.0209  92000  0.466  0.863  0.909  0.0245
 21 0.891  0.0384  21.088   0.858  0.0216  86000  0.478  0.864  0.904  0.0235
 22 0.913  0.0348  20.695   0.857  0.0224  79000  0.488  0.864  0.898  0.0226
 23 0.931  0.0310  20.354   0.856  0.0234  72000  0.498  0.865  0.892  0.0218
 24 0.948  0.0271  20.063   0.856  0.0247  64000  0.507  0.866  0.885  0.0211
 25 0.963  0.0232  19.819   0.855  0.0262  56000  0.514  0.866  0.877  0.0206
 26 0.975  0.0192  19.619   0.855  0.0283  47000  0.520  0.866  0.868  0.0201
 27 0.985  0.0151  19.462   0.854  0.0311  37000  0.525  0.867  0.855  0.0198
 28 0.992  0.0111  19.345   0.854  0.0351  28000  0.529  0.866  0.838  0.0195
 29 0.997  0.0073  19.267   0.851  0.0415  18000  0.532  0.865  0.813  0.0193
 30 0.999  0.0044  19.229   0.834  0.0508  11000  0.533  0.856  0.778  0.0192
```

```
=====
Free Tip Potential Formulation Solution:
                                Wake adv. ratio: 0.22660
no. blades : 6                  radius(m) : 0.2000    adv. ratio: 0.19099
thrust(N)   : 45.128            torque(N-m): 2.1695    power(W)  : 1931.135
Efficiency  : 0.7945           speed(m/s) : 34.000    rpm       : 8500.000
Eff induced : 0.8705           Eff ideal   : 0.8979    Tcoef     : 0.5068
Tnacel(N)   : 1.4486           hub rad.(m): 0.0632    disp. rad.: 0.0632
rho(kg/m3)  : 1.22600          Vsound(m/s): 340.000   mu(kg/m-s): 0.1780E-04

-----
Ct: 0.07164      Cp: 0.05410      J: 0.60000

  i   r/R   c/R   beta(deg)   CL   Cd   Re   Mach   effi   effp   na.u/U
  1  0.318  0.0417  44.759  1.033  0.0278 39000 0.198  0.905  0.945  0.0813
  2  0.326  0.0414  44.128  1.030  0.0277 39000 0.202  0.903  0.945  0.0797
  3  0.340  0.0413  42.952  1.022  0.0274 40000 0.208  0.897  0.944  0.0768
  4  0.361  0.0416  41.376  1.011  0.0268 42000 0.217  0.891  0.944  0.0729
  5  0.386  0.0423  39.557  0.998  0.0260 45000 0.229  0.885  0.943  0.0684
  6  0.416  0.0430  37.639  0.983  0.0253 49000 0.242  0.880  0.942  0.0637
  7  0.448  0.0435  35.729  0.969  0.0246 52000 0.257  0.875  0.941  0.0591
  8  0.481  0.0437  33.899  0.955  0.0239 56000 0.273  0.872  0.939  0.0547
  9  0.516  0.0435  32.188  0.942  0.0235 59000 0.290  0.870  0.936  0.0505
 10 0.552  0.0430  30.615  0.929  0.0231 62000 0.307  0.868  0.934  0.0467
 11 0.588  0.0422  29.186  0.918  0.0228 64000 0.325  0.867  0.931  0.0432
 12 0.623  0.0413  27.896  0.907  0.0226 66000 0.342  0.866  0.928  0.0401
 13 0.658  0.0402  26.737  0.898  0.0225 68000 0.360  0.866  0.924  0.0372
 14 0.692  0.0389  25.699  0.890  0.0225 69000 0.377  0.866  0.921  0.0347
 15 0.725  0.0376  24.772  0.883  0.0226 69000 0.393  0.866  0.917  0.0325
 16 0.757  0.0362  23.945  0.877  0.0227 69000 0.409  0.867  0.913  0.0305
 17 0.787  0.0347  23.209  0.872  0.0229 69000 0.425  0.867  0.909  0.0287
 18 0.816  0.0330  22.555  0.869  0.0232 68000 0.439  0.868  0.905  0.0271
 19 0.843  0.0312  21.975  0.866  0.0236 66000 0.453  0.869  0.901  0.0257
 20 0.868  0.0293  21.463  0.864  0.0241 64000 0.466  0.870  0.896  0.0245
 21 0.891  0.0272  21.014  0.863  0.0248 61000 0.478  0.871  0.891  0.0235
 22 0.913  0.0249  20.622  0.862  0.0256 57000 0.488  0.872  0.885  0.0226
 23 0.931  0.0224  20.282  0.862  0.0267 52000 0.498  0.873  0.879  0.0218
 24 0.948  0.0198  19.992  0.862  0.0280 47000 0.507  0.874  0.872  0.0211
 25 0.963  0.0171  19.749  0.862  0.0297 41000 0.514  0.875  0.863  0.0206
 26 0.975  0.0142  19.550  0.862  0.0319 35000 0.520  0.875  0.853  0.0201
 27 0.985  0.0113  19.393  0.862  0.0350 28000 0.525  0.876  0.840  0.0198
 28 0.992  0.0083  19.276  0.862  0.0396 21000 0.529  0.876  0.821  0.0195
 29 0.997  0.0054  19.199  0.861  0.0469 14000 0.532  0.876  0.794  0.0193
 30 0.999  0.0031  19.161  0.851  0.0586  8000 0.533  0.870  0.753  0.0192
```

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Free Tip Potential Formulation Solution:

no. blades : 10	radius(m) : 0.2000	Wake adv. ratio: 0.22455
thrust(N) : 43.959	torque(N-m): 2.1433	adv. ratio: 0.19099
Efficiency : 0.7834	speed(m/s) : 34.000	power(W) : 1907.774
Eff induced: 0.8780	Eff ideal : 0.9000	rpm : 8500.000
Tnacel(N) : 1.3905	hub rad.(m): 0.0632	Tcoef : 0.4937
rho(kg/m3) : 1.22600	Vsound(m/s): 340.000	disp. rad.: 0.0632
		mu(kg/m-s): 0.1780E-04

Ct: 0.06979 Cp: 0.05345 J: 0.60000

i	r/R	c/R	beta(deg)	CL	Cd	Re	Mach	effi	effp	na.u/U
1	0.318	0.0203	44.691	1.055	0.0373	19000	0.198	0.915	0.929	0.0813
2	0.326	0.0202	44.057	1.051	0.0371	19000	0.202	0.912	0.928	0.0797
3	0.340	0.0205	42.876	1.042	0.0364	20000	0.208	0.907	0.928	0.0768
4	0.361	0.0212	41.293	1.030	0.0353	22000	0.217	0.900	0.928	0.0729
5	0.386	0.0221	39.470	1.015	0.0339	24000	0.229	0.894	0.928	0.0684
6	0.416	0.0229	37.549	0.999	0.0326	26000	0.242	0.889	0.927	0.0637
7	0.448	0.0235	35.639	0.984	0.0315	28000	0.257	0.884	0.925	0.0591
8	0.481	0.0238	33.808	0.969	0.0306	30000	0.273	0.881	0.923	0.0547
9	0.516	0.0238	32.099	0.955	0.0299	32000	0.290	0.878	0.921	0.0505
10	0.552	0.0236	30.528	0.941	0.0294	34000	0.307	0.877	0.917	0.0467
11	0.588	0.0233	29.101	0.929	0.0290	35000	0.325	0.875	0.914	0.0432
12	0.623	0.0228	27.813	0.918	0.0287	37000	0.342	0.875	0.910	0.0401
13	0.658	0.0223	26.657	0.908	0.0286	38000	0.360	0.874	0.906	0.0372
14	0.692	0.0218	25.622	0.899	0.0285	38000	0.377	0.874	0.902	0.0347
15	0.725	0.0212	24.697	0.891	0.0284	39000	0.393	0.874	0.898	0.0325
16	0.757	0.0206	23.872	0.884	0.0285	40000	0.409	0.874	0.893	0.0305
17	0.787	0.0200	23.138	0.878	0.0286	40000	0.425	0.874	0.889	0.0287
18	0.816	0.0194	22.485	0.873	0.0287	40000	0.439	0.875	0.885	0.0271
19	0.843	0.0187	21.907	0.870	0.0290	40000	0.453	0.875	0.880	0.0257
20	0.868	0.0179	21.397	0.867	0.0294	39000	0.466	0.876	0.876	0.0245
21	0.891	0.0170	20.949	0.866	0.0299	38000	0.478	0.877	0.871	0.0235
22	0.913	0.0160	20.558	0.865	0.0306	36000	0.488	0.878	0.865	0.0226
23	0.931	0.0147	20.220	0.866	0.0316	34000	0.498	0.879	0.859	0.0218
24	0.948	0.0133	19.931	0.866	0.0329	31000	0.507	0.881	0.852	0.0211
25	0.963	0.0116	19.688	0.867	0.0346	28000	0.514	0.882	0.844	0.0206
26	0.975	0.0098	19.490	0.868	0.0370	24000	0.520	0.883	0.833	0.0201
27	0.985	0.0079	19.333	0.869	0.0405	19000	0.525	0.884	0.819	0.0198
28	0.992	0.0059	19.217	0.869	0.0456	15000	0.529	0.885	0.799	0.0195
29	0.997	0.0038	19.140	0.869	0.0541	10000	0.532	0.885	0.769	0.0193
30	0.999	0.0021	19.102	0.866	0.0684	5000	0.533	0.883	0.723	0.0192

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=====
Free Tip Potential Formulation Solution:
                                Wake adv. ratio: 0.22537
no. blades : 8                  radius(m) : 0.2000    adv. ratio: 0.19099
thrust(N)   : 44.522            torque(N-m): 2.1555    power(W)  : 1918.671
Efficiency  : 0.7890           speed(m/s) : 34.000    rpm       : 8500.000
Eff induced : 0.8750           Eff ideal   : 0.8990    Tcoef     : 0.5000
Tnacel(N)   : 1.4160           hub rad.(m): 0.0632    disp. rad.: 0.0632
rho(kg/m3)  : 1.22600          Vsound(m/s): 340.000   mu(kg/m-s): 0.1780E-04

-----
Ct: 0.07068      Cp: 0.05375      J: 0.60000

i r/R c/R beta(deg) CL Cd Re Mach effi efffp na.u/U
1 0.318 0.0277 44.718 1.047 0.0329 26000 0.198 0.911 0.936 0.0813
2 0.326 0.0275 44.085 1.043 0.0328 26000 0.202 0.908 0.936 0.0797
3 0.340 0.0276 42.906 1.034 0.0322 27000 0.208 0.903 0.935 0.0768
4 0.361 0.0282 41.326 1.022 0.0314 29000 0.217 0.897 0.935 0.0729
5 0.386 0.0291 39.504 1.008 0.0303 31000 0.229 0.891 0.935 0.0684
6 0.416 0.0300 37.585 0.993 0.0293 34000 0.242 0.885 0.934 0.0637
7 0.448 0.0306 35.674 0.978 0.0283 37000 0.257 0.881 0.932 0.0591
8 0.481 0.0309 33.844 0.963 0.0276 40000 0.273 0.877 0.930 0.0547
9 0.516 0.0309 32.134 0.949 0.0269 42000 0.290 0.875 0.928 0.0505
10 0.552 0.0306 30.562 0.936 0.0265 44000 0.307 0.873 0.925 0.0467
11 0.588 0.0302 29.134 0.924 0.0261 46000 0.325 0.872 0.922 0.0432
12 0.623 0.0296 27.846 0.913 0.0259 47000 0.342 0.871 0.918 0.0401
13 0.658 0.0289 26.688 0.903 0.0257 49000 0.360 0.871 0.914 0.0372
14 0.692 0.0281 25.652 0.895 0.0257 50000 0.377 0.871 0.911 0.0347
15 0.725 0.0273 24.726 0.887 0.0257 50000 0.393 0.871 0.907 0.0325
16 0.757 0.0265 23.901 0.881 0.0258 51000 0.409 0.871 0.903 0.0305
17 0.787 0.0256 23.165 0.875 0.0259 51000 0.425 0.871 0.898 0.0287
18 0.816 0.0246 22.512 0.871 0.0261 51000 0.439 0.872 0.894 0.0271
19 0.843 0.0235 21.934 0.868 0.0265 50000 0.453 0.873 0.890 0.0257
20 0.868 0.0223 21.423 0.866 0.0269 49000 0.466 0.873 0.885 0.0245
21 0.891 0.0210 20.974 0.865 0.0275 47000 0.478 0.875 0.880 0.0235
22 0.913 0.0195 20.583 0.864 0.0283 45000 0.488 0.876 0.875 0.0226
23 0.931 0.0177 20.244 0.864 0.0293 41000 0.498 0.877 0.868 0.0218
24 0.948 0.0158 19.955 0.865 0.0306 38000 0.507 0.878 0.861 0.0211
25 0.963 0.0138 19.712 0.865 0.0324 33000 0.514 0.879 0.853 0.0206
26 0.975 0.0116 19.513 0.866 0.0347 28000 0.520 0.880 0.842 0.0201
27 0.985 0.0092 19.356 0.866 0.0380 23000 0.525 0.881 0.828 0.0198
28 0.992 0.0068 19.240 0.866 0.0429 17000 0.529 0.881 0.809 0.0195
29 0.997 0.0044 19.163 0.866 0.0509 11000 0.532 0.881 0.780 0.0193
30 0.999 0.0025 19.125 0.860 0.0641 6000 0.533 0.878 0.736 0.0192
```

$$V/\Omega R = 0.1910$$

$$J = 0.6000$$

$$\beta_{tip} = 19.229$$

$$P_C = 0.6423$$

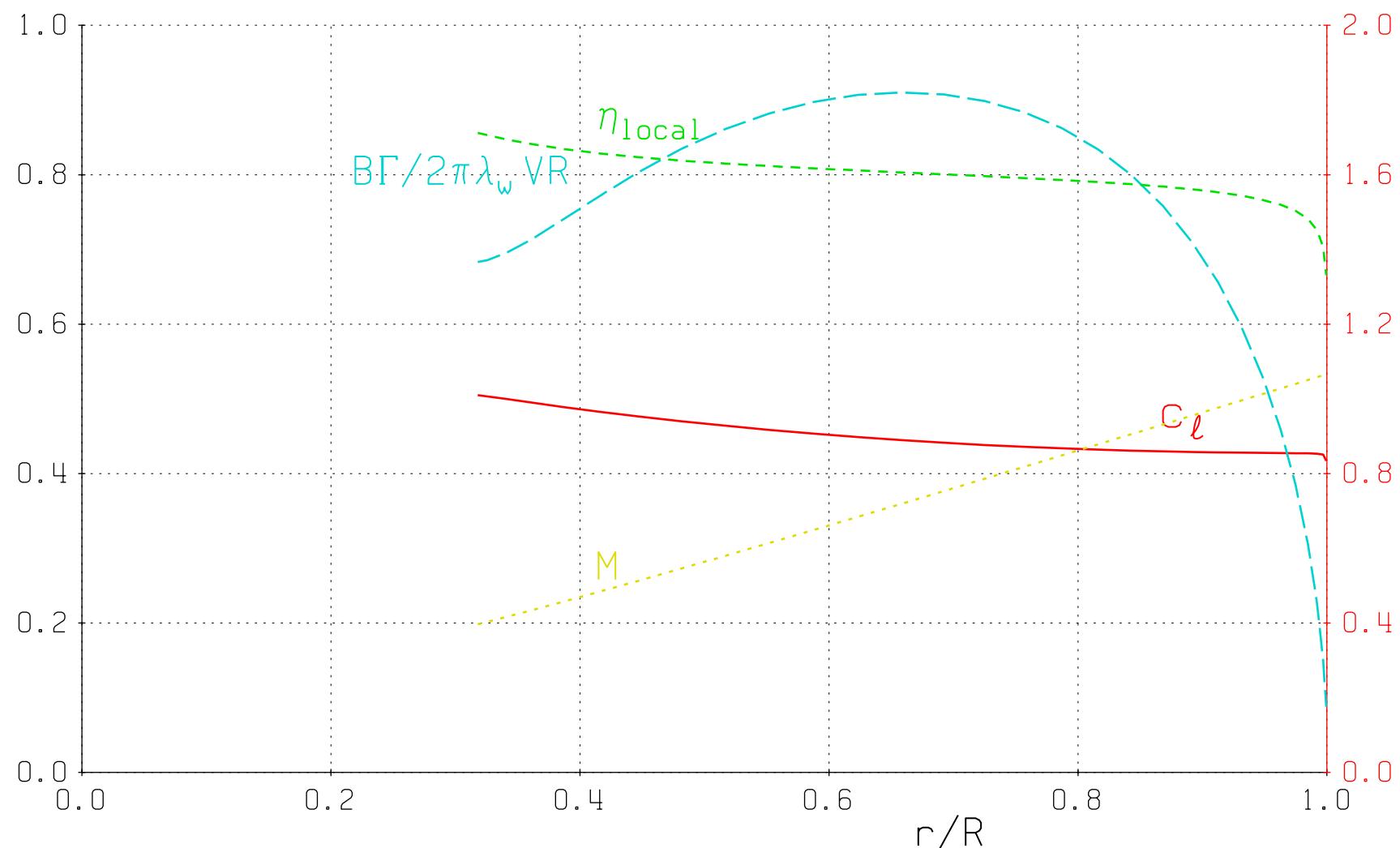
$$C_P = 0.0545$$

$$n_{ideal} = 0.8626$$

$$T_C = 0.5132$$

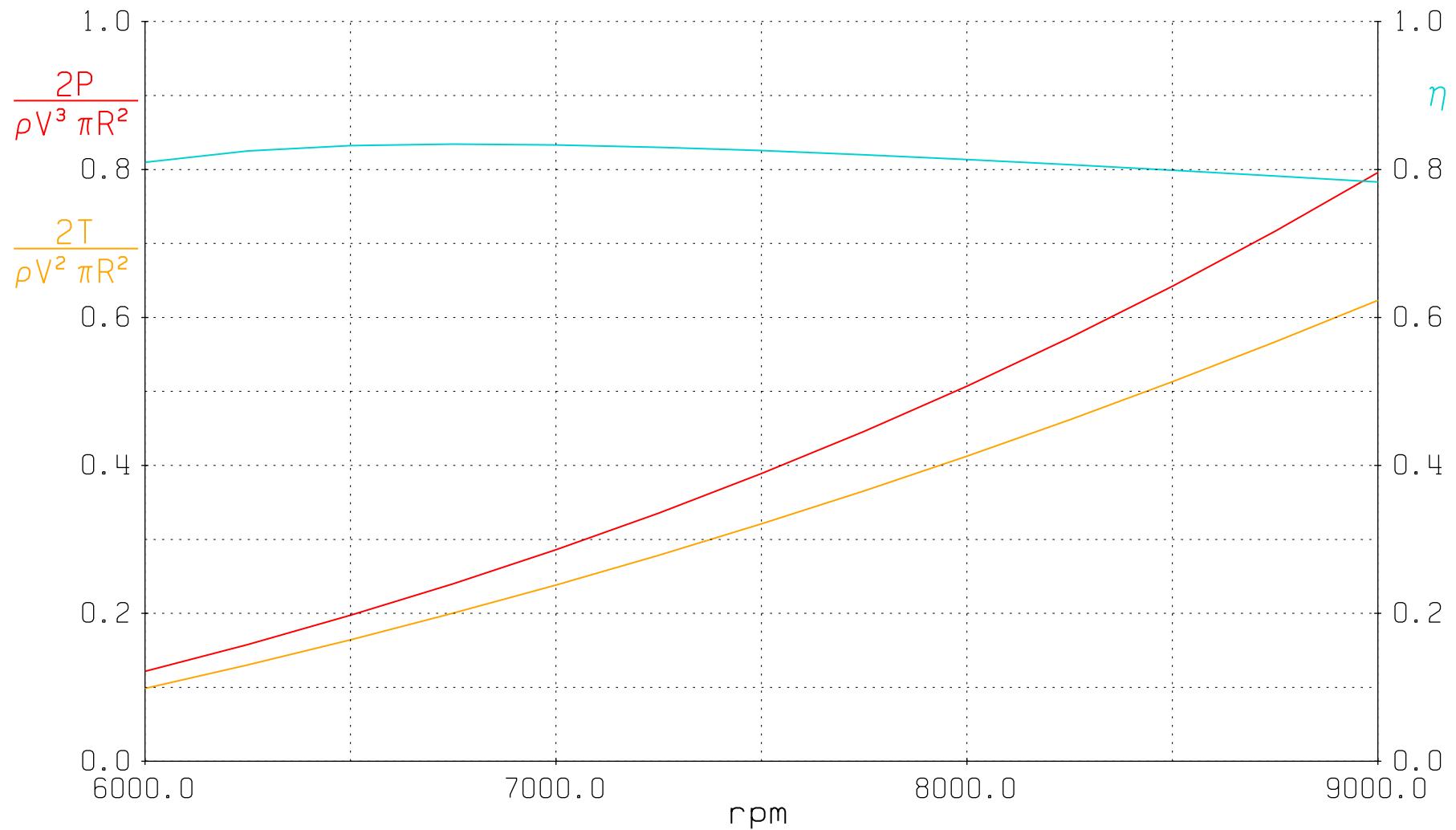
$$C_T = 0.0726$$

$$\eta = 0.7990$$



$$\begin{aligned} V &= 34.00 \\ \beta_{tip} &= 19.229 \end{aligned}$$

$$\begin{aligned} \rho &= 1.2260 \\ R &= 0.2000 \end{aligned}$$



$$M_{\infty} = 0.100$$

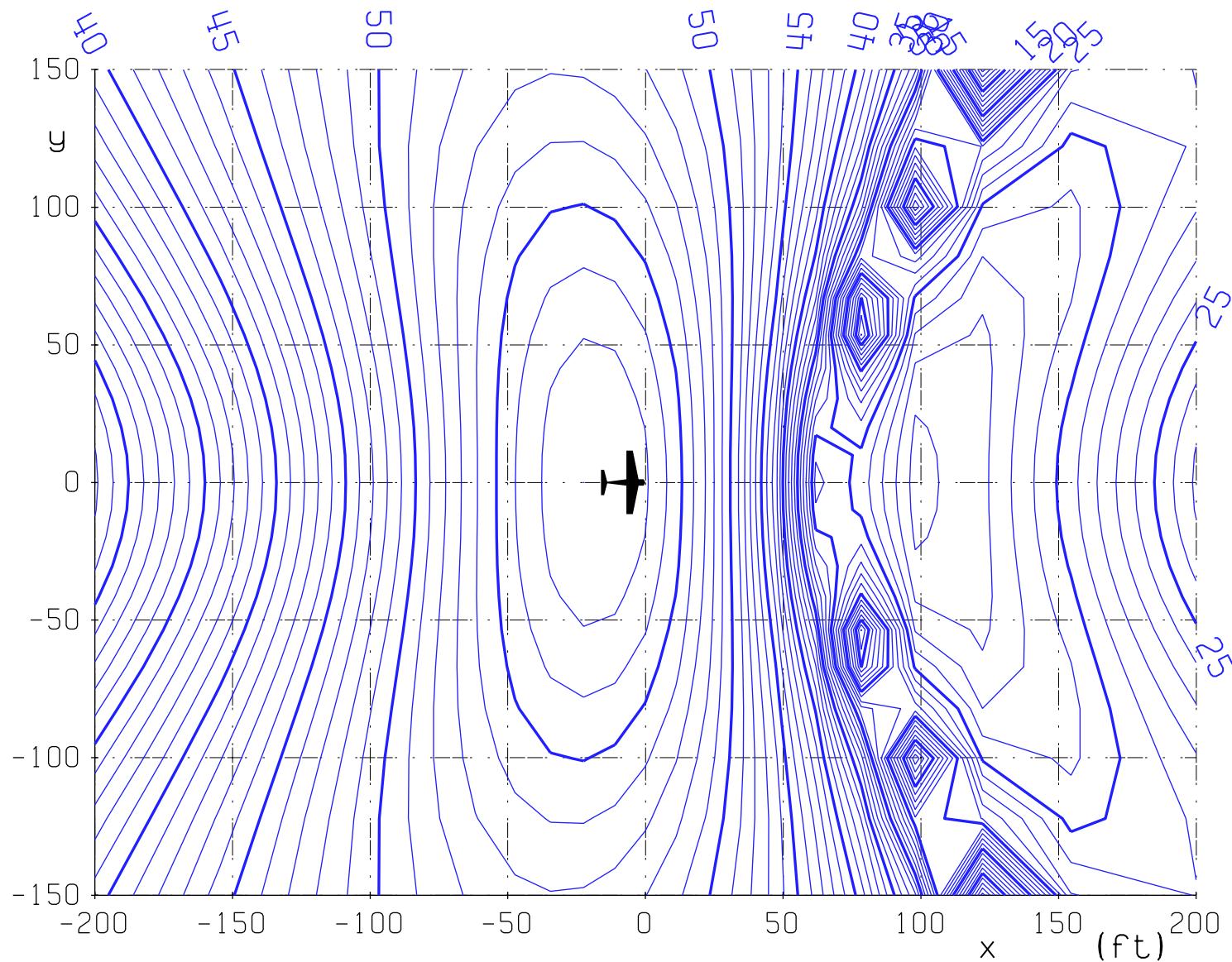
$$V/\Omega R = 0.191$$

$$M_{tip} = 0.533$$

$$C_p = 0.054$$

$$\text{Altitude} = 100 \text{ ft}$$

$$\text{Climb angle} = 0^\circ$$



$$V/\Omega R = 0.1910$$

$$J = 0.6000$$

$$\beta_{tip} = 19.161$$

$$P_C = 0.6378$$

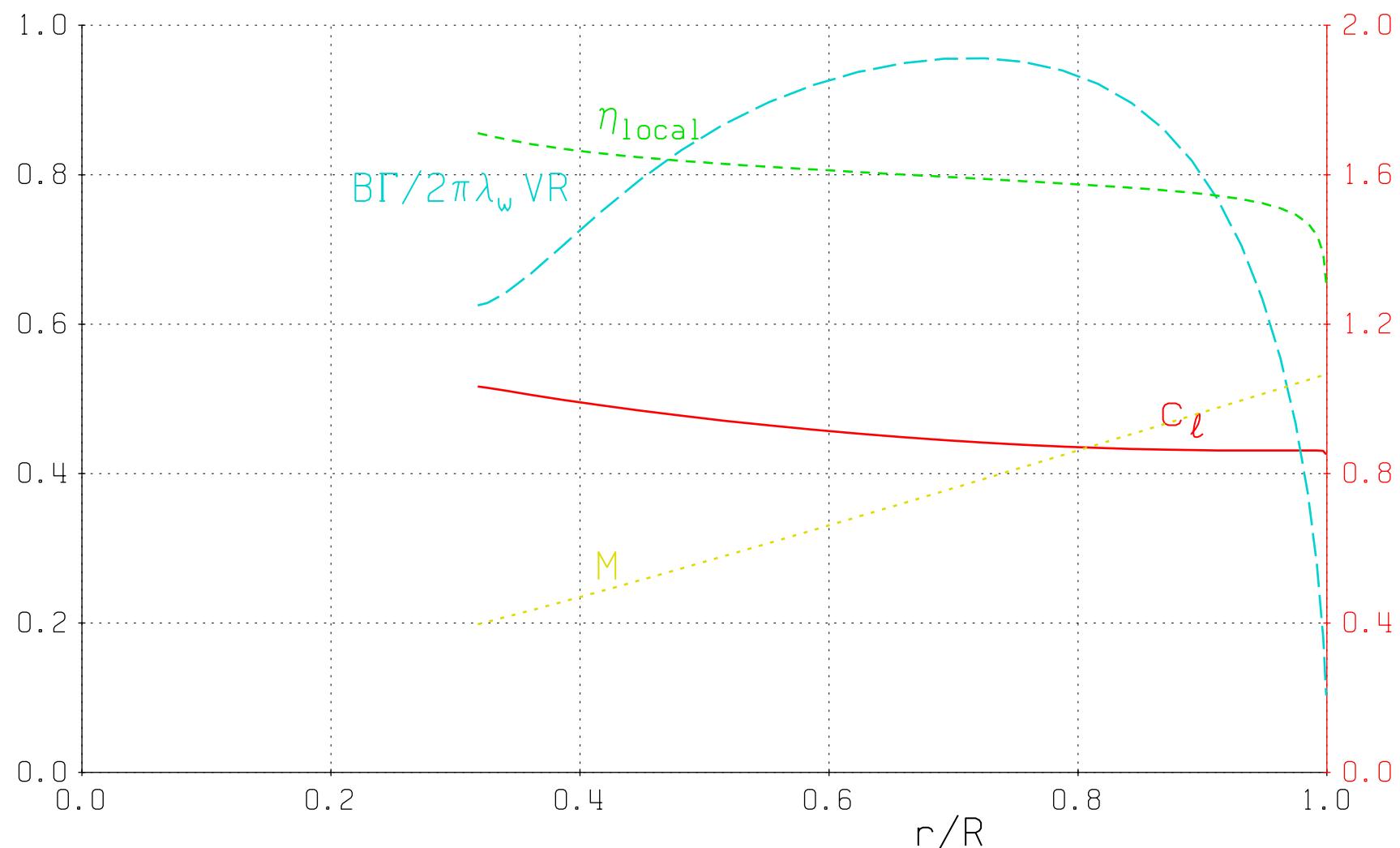
$$C_P = 0.0541$$

$$n_{ideal} = 0.8705$$

$$T_C = 0.5068$$

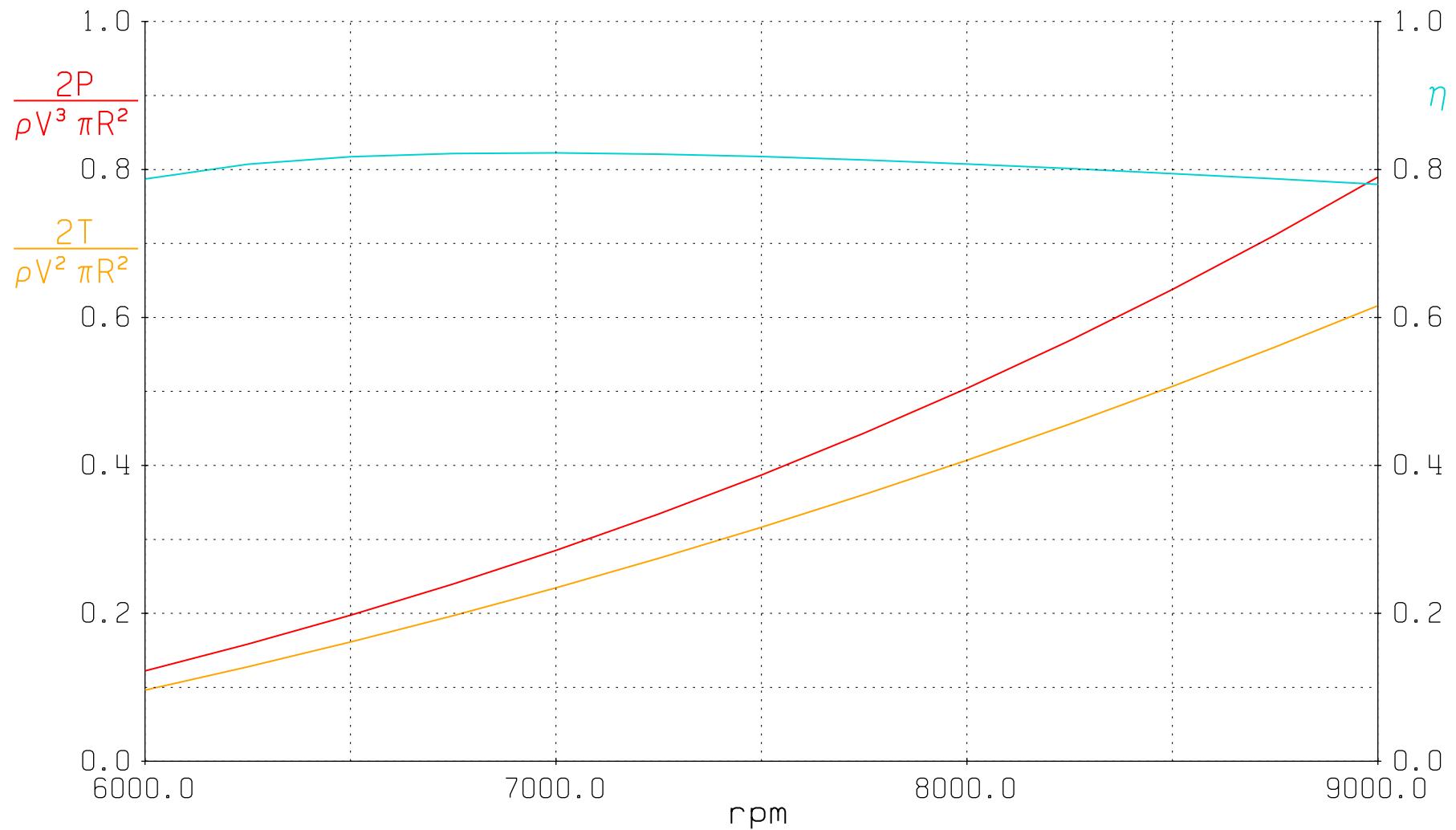
$$C_T = 0.0716$$

$$\eta = 0.7945$$



$$V = 34.00$$
$$\beta_{tip} = 19.161$$

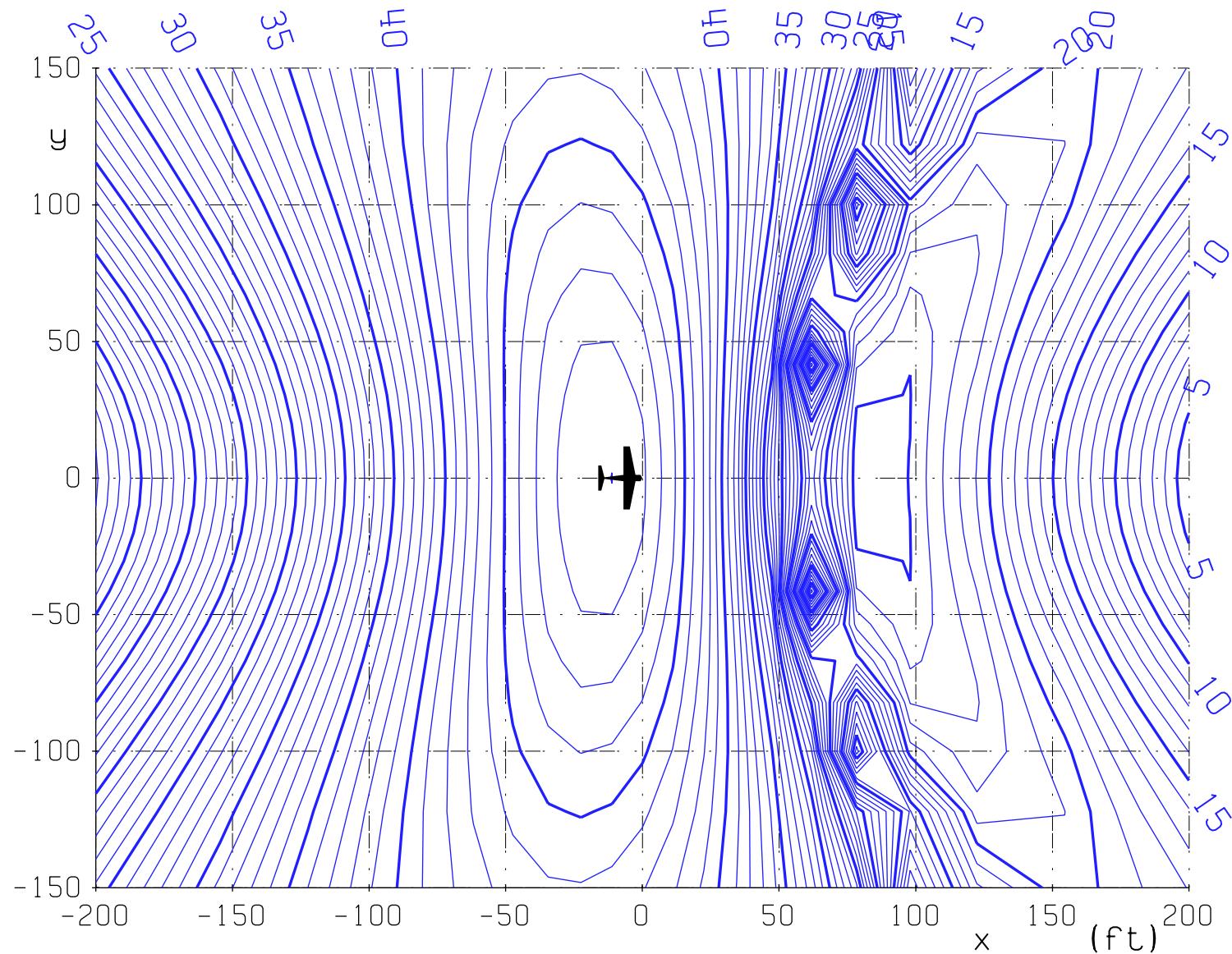
$$\rho = 1.2260$$
$$R = 0.2000$$



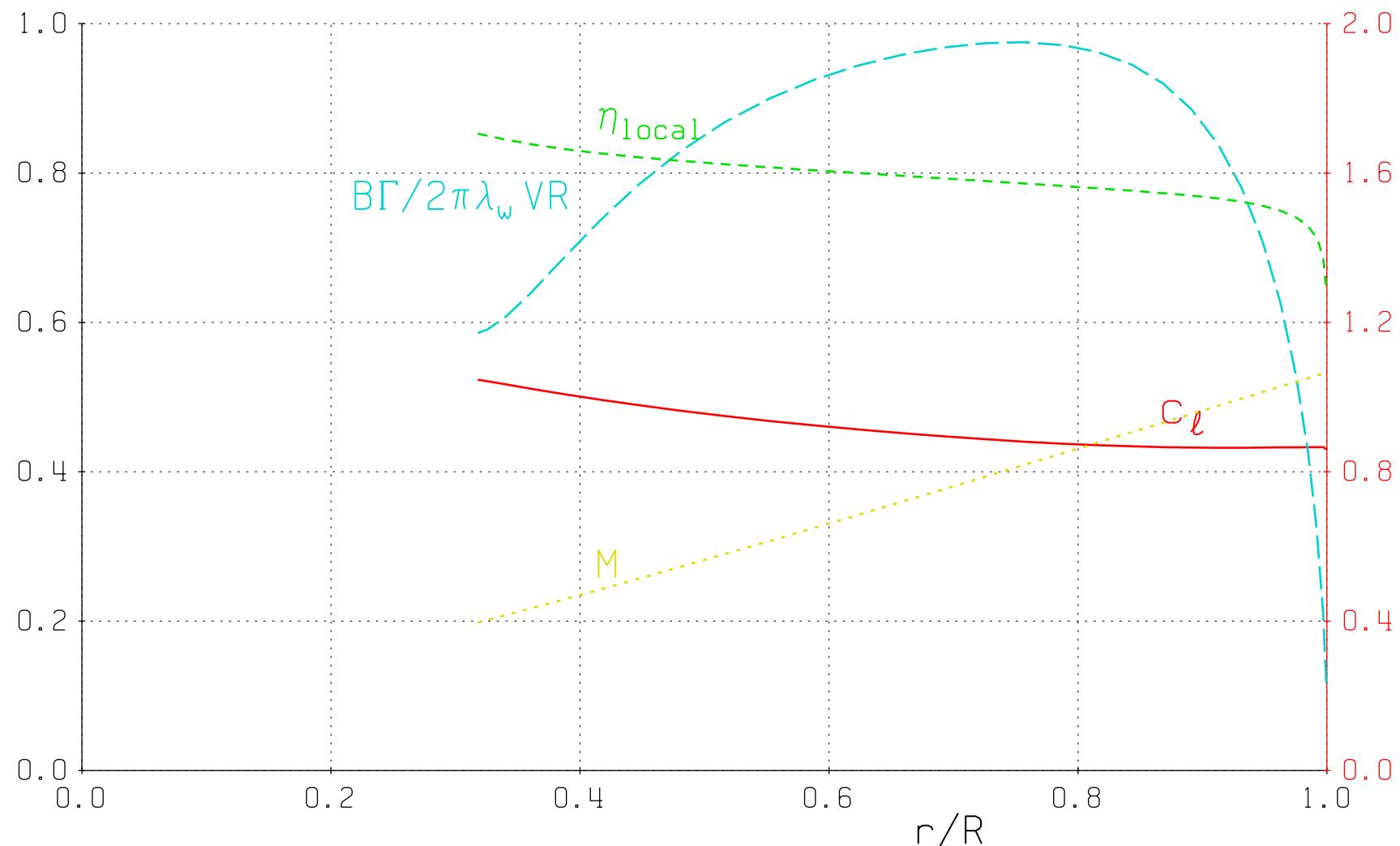
$$M_{\infty} = 0.100 \quad V/\Omega R = 0.191$$

$$M_{tip} = 0.533 \quad C_p = 0.054$$

$$\text{Altitude} = 100 \text{ ft} \quad \text{Climb angle} = 0^\circ$$

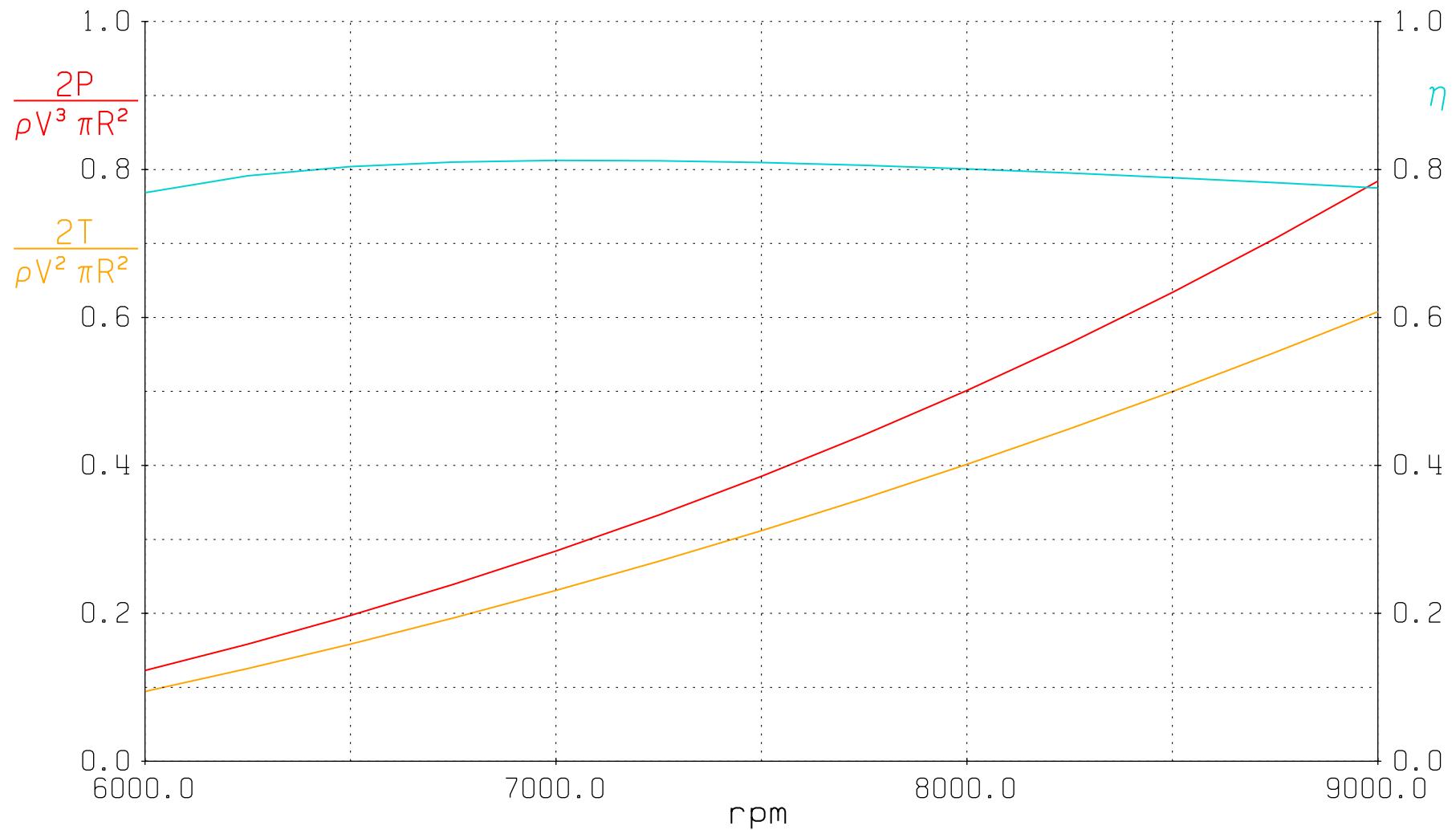


$V/\Omega R = 0.1910$	$J = 0.6000$	$\beta_{tip} = 19.125$
$P_C = 0.6337$	$C_P = 0.0538$	$n_{ideal} = 0.8750$
$T_C = 0.5000$	$C_T = 0.0707$	$\eta = 0.7890$



$$V = 34.00$$
$$\beta_{tip} = 19.125$$

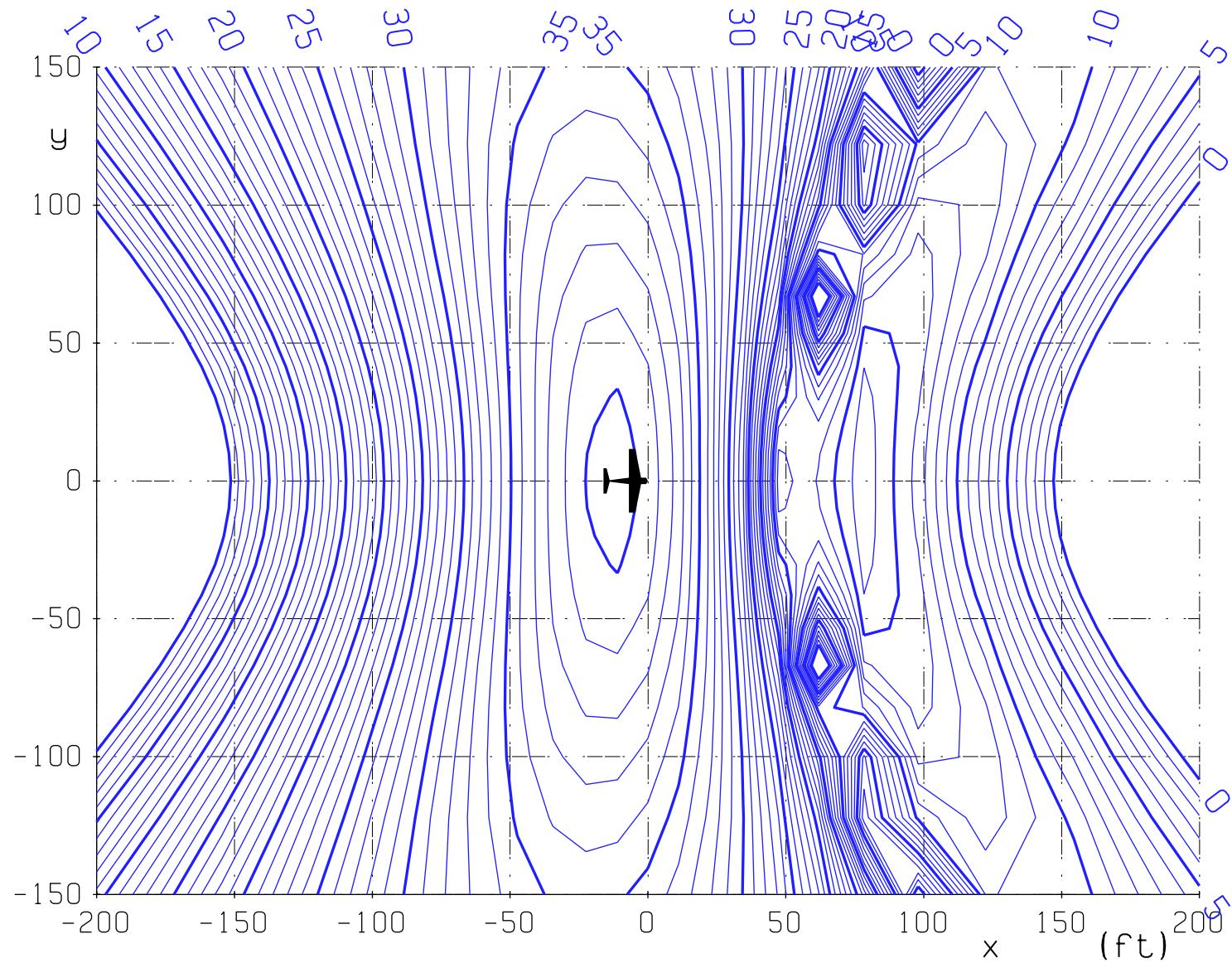
$$\rho = 1.2260$$
$$R = 0.2000$$



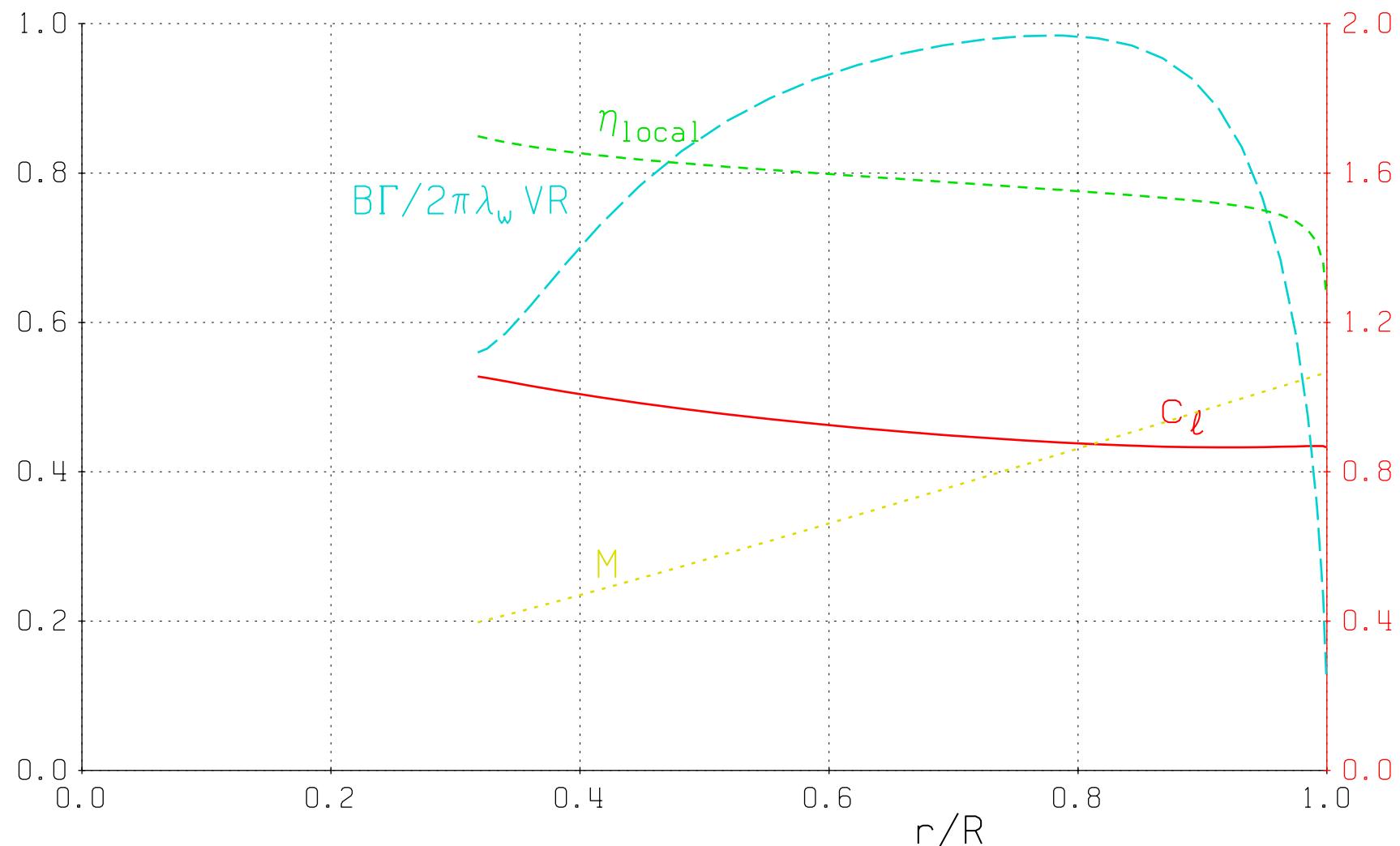
$$M_{\infty} = 0.100 \quad V/\Omega R = 0.191$$

$$M_{tip} = 0.533 \quad C_p = 0.054$$

Altitude = 100 ft Climb angle = 0°

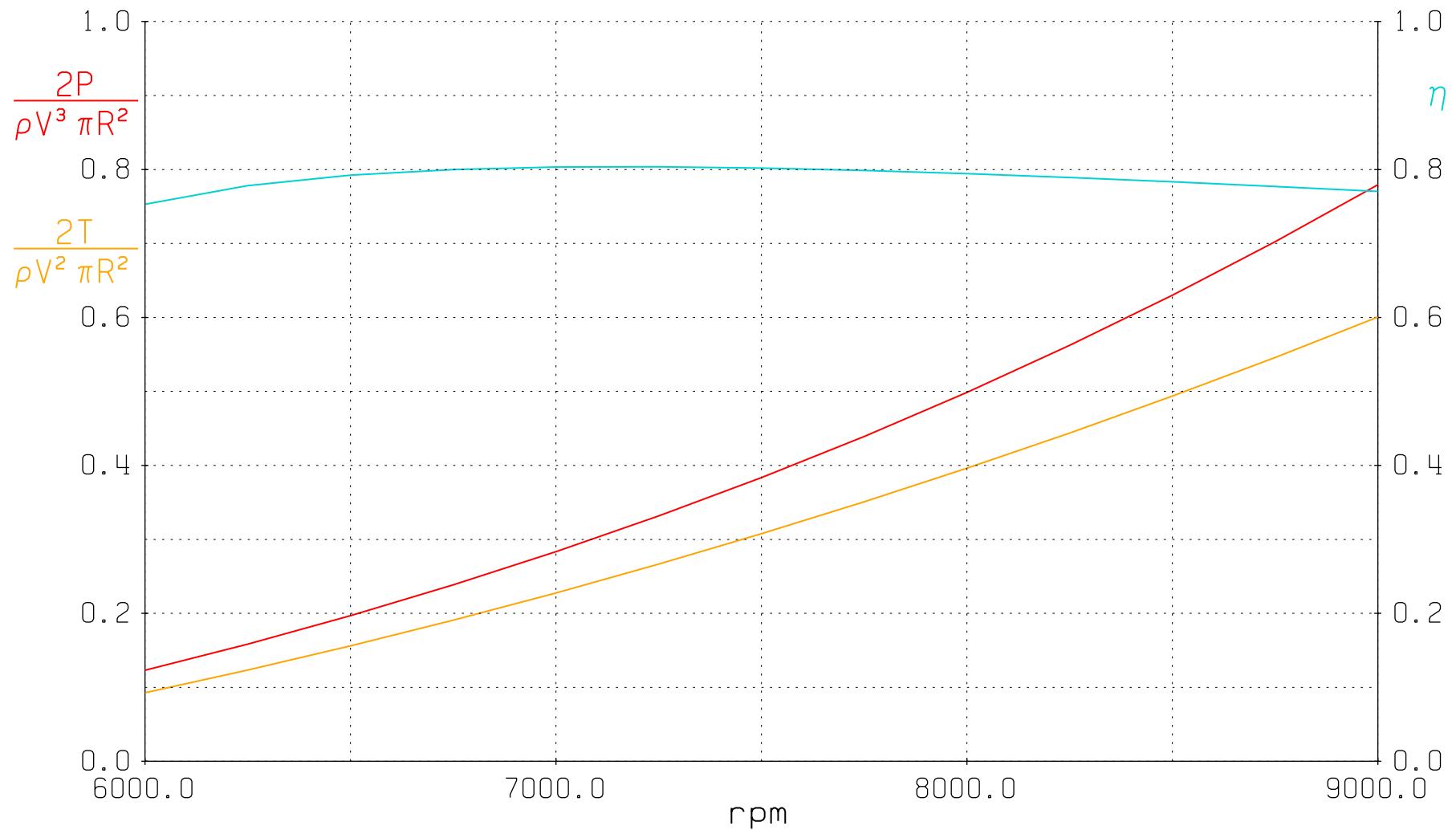


$V/\Omega R = 0.1910$	$J = 0.6000$	$\beta_{tip} = 19.102$
$P_c = 0.6301$	$C_p = 0.0534$	$n_{ideal} = 0.8780$
$T_c = 0.4937$	$C_T = 0.0698$	$\eta = 0.7834$



$$V = 34.00$$
$$\beta_{tip} = 19.102$$

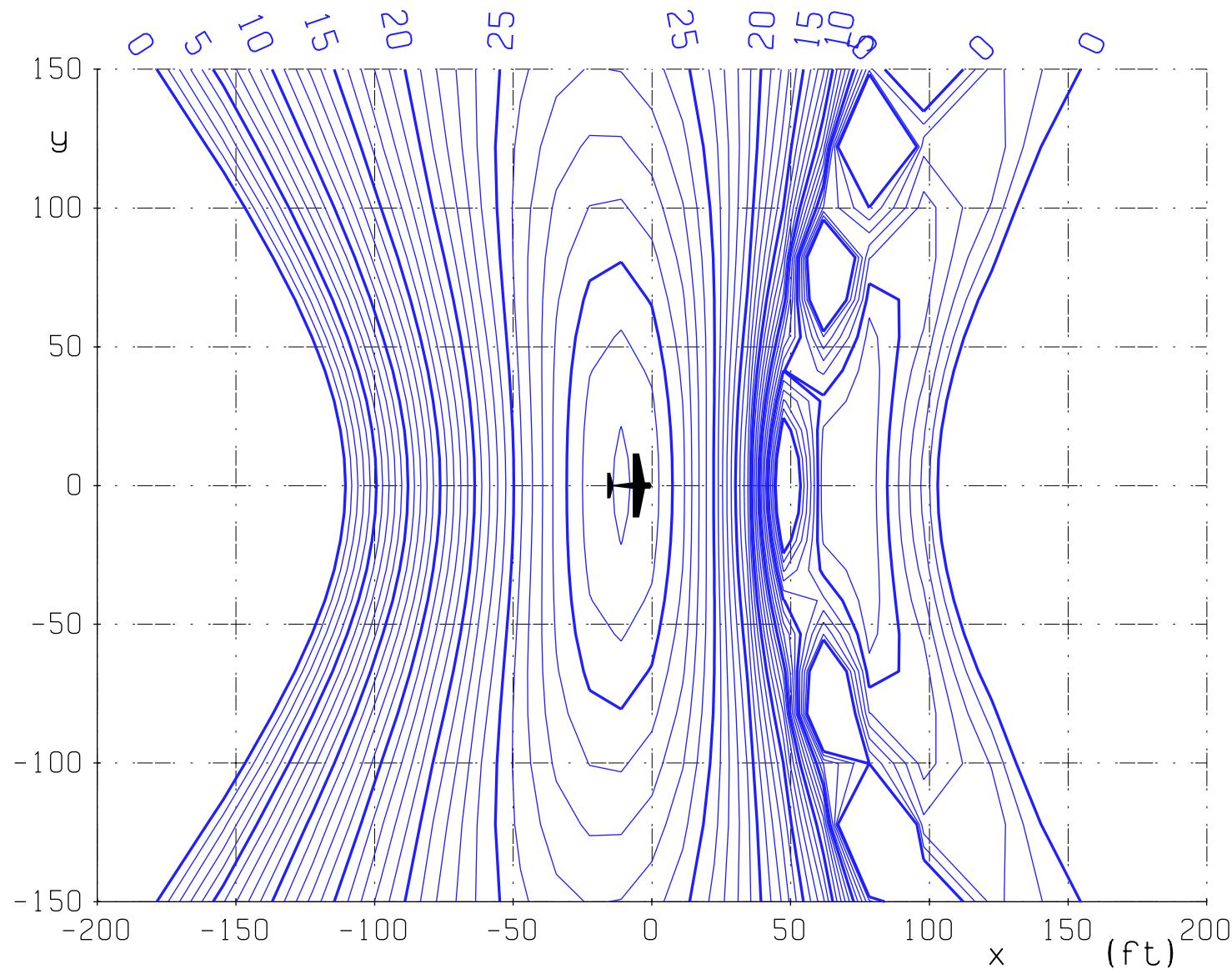
$$\rho = 1.2260$$
$$R = 0.2000$$



$$M_{\infty} = 0.100 \quad V/\Omega R = 0.191$$

$$M_{tip} = 0.533 \quad C_p = 0.053$$

Altitude = 100 ft Climb angle = 0°



Sensitivity of Noise to Blade Number

